THE NATURE OF RADIOACTIVE FALL-OUT AND ITS EFFECTS ON MAN

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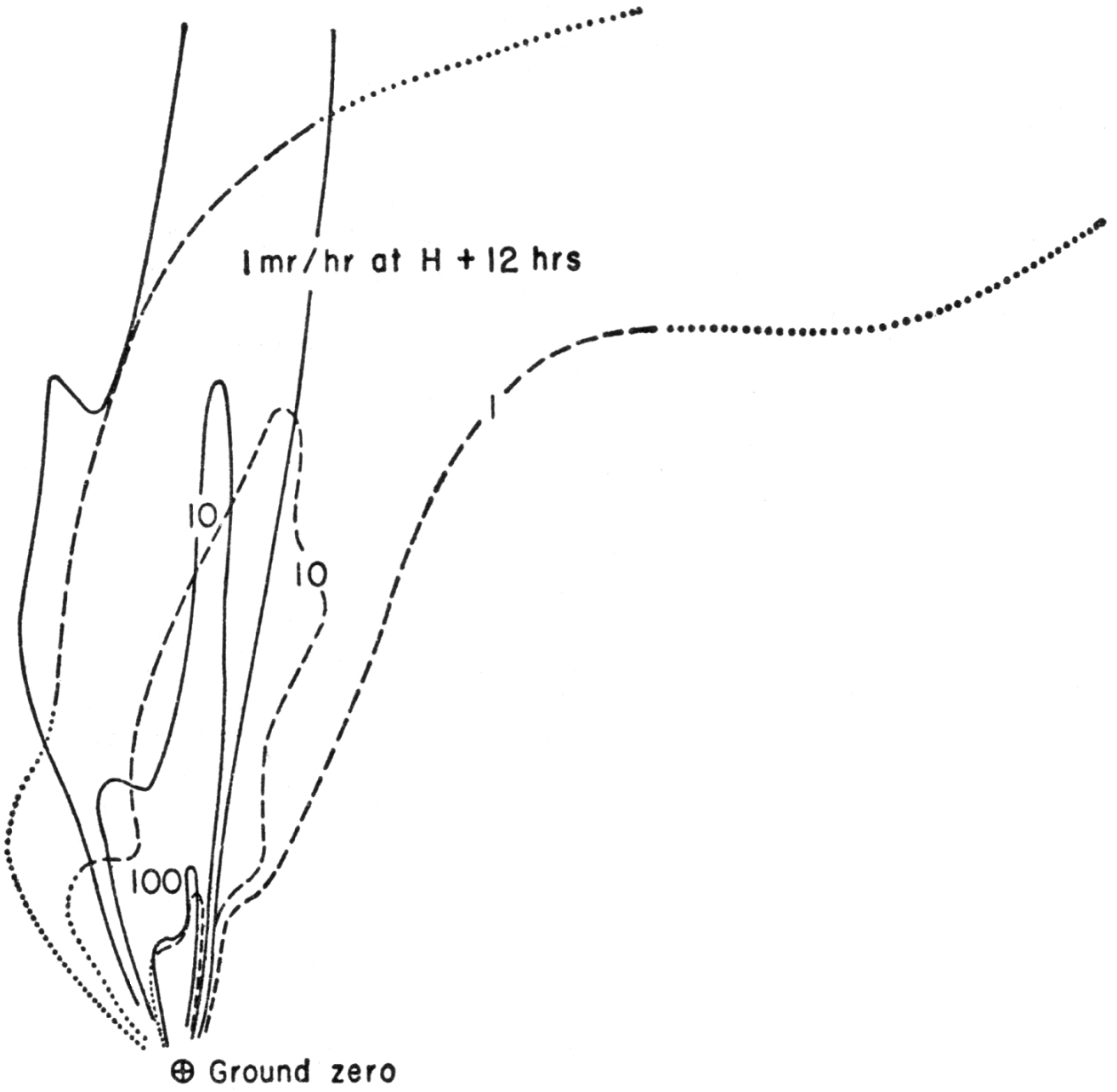

FIGURE 4.—The observed fallout distribution (dashed lines) and the pattern computed by the Weather Bureau using winds predicted at H–2 hours. May 5, 1955.

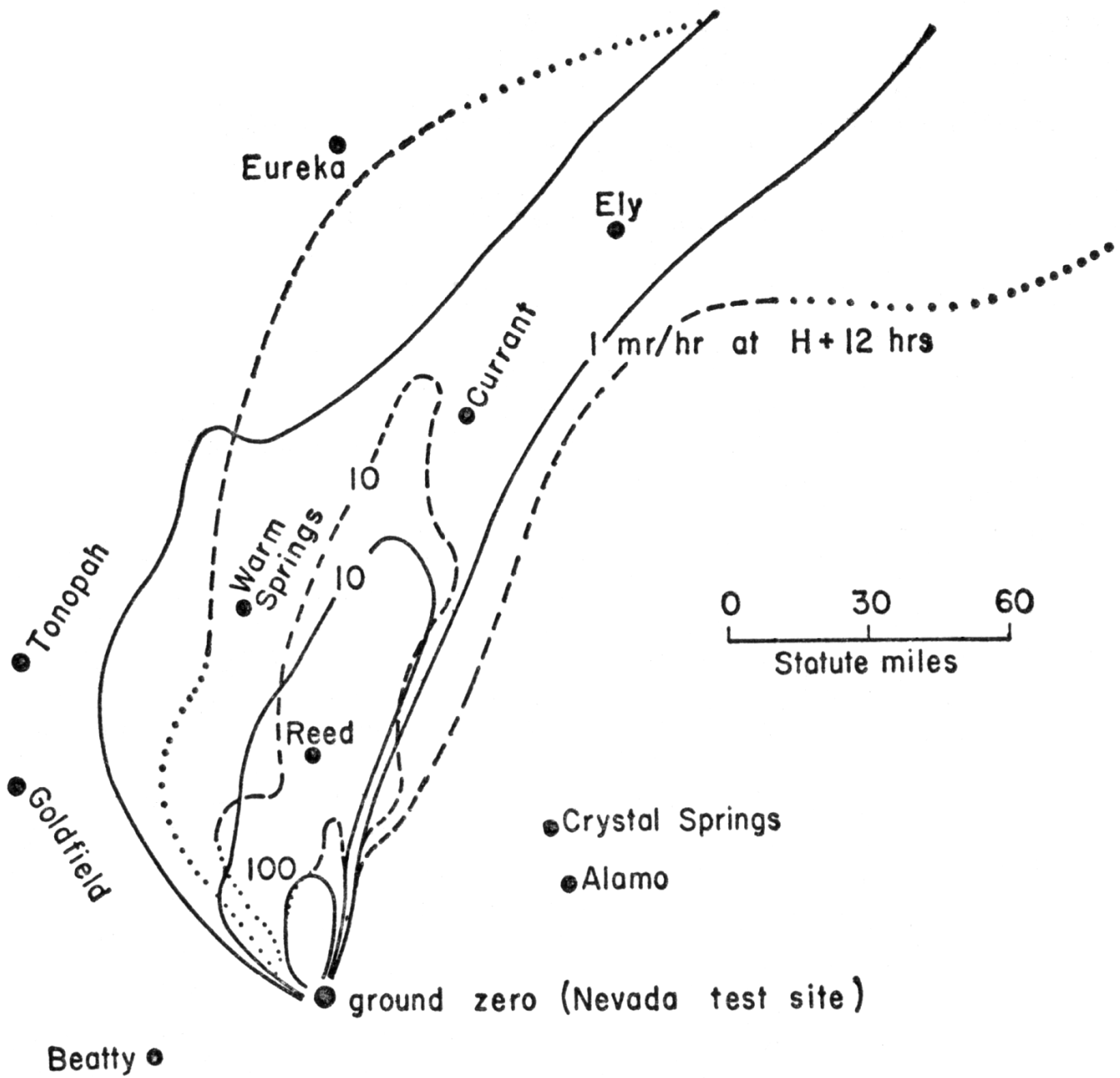

FIGURE 6.—The observed fallout distribution (dashed lines) and the pattern reconstructed by the Weather Bureau using a hand computation with time and space variation of winds (solid lines). May 5, 1955.

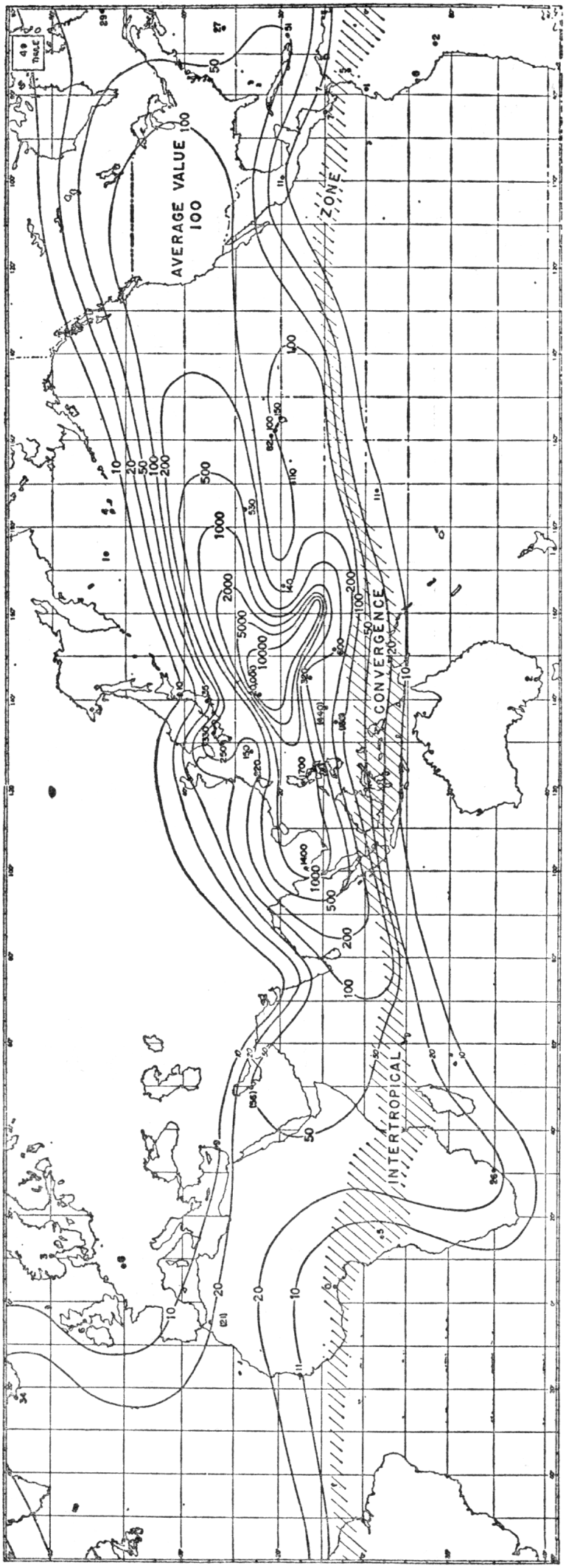

FIGURE 4.—Total radioactive fallout from the Mike cloud in the period from 2 to 35 days after detonation, in millicuries per 100 square miles. Hatching indicates the approximate November position of the Intertropical Convergence Zone, the belt of low pressure that tends to separate Northern and Southern Hemisphere air near the surface of the earth.

A Fallout Forecasting Technique With Results Obtained at the Eniwetok Proving Ground [Draft]

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ADMINISTRATIVE INFORMATION

The work described herein is a part of the research sponsored by BuShips and the United States Army and locally designated as program 2, problem 3, phase 3. Its technical objective is AW–7 and it is described on RDB card NS 081–001.

SUMMARY

The problem: A fallout forecasting technique is needed to qualitatively describe the fallout hazard resulting from nuclear detonations. This technique should have such flexibility that its employment is valid for field use.

Findings: A summary of the latest experimental and theoretical considerations has resulted in the development of a technique whose complexity is dependent on the required accuracy of the results desired. This technique has been satisfactorily tested at the Eniwetok Proving Grounds for land surface and water surface bursts.

ABSTRACT

A generalized fallout forecasting technique is presented with detailed computations of input parameters for use in the Marshal Islands.

Results obtained at a recent weapons test are briefly discussed by comparison of forecast fallout with preliminary measured data.

1. INTRODUCTION

Fallout research continues to seek a theoretical working model that will describe in detail the mechanism of fallout. Aside from this long-range problem, consideration must be given to making available a working tool that will meet the needs of the military for solving fallout problems in the field. Such consideration requires a simplified rapid system capable of producing qualitative if not quantitative results.

Within a program studying fallout at a recent weapons test operation there was a fallout forecasting assignment that had many aspects of the practical

field problem yet, at the same time required quantitative results for use in reducing other data. This program needed positioning data such that three ships could be located properly in the fallout to obtain data on its parameters. Also, aerial and oceanographic survey projects required knowledge of the fallout to instigate their navigational procedures properly.

To meet these requirements a technique for rapid fallout forecasting was developed which not only satisfied the needs of the fallout program but also was accurate enough to allow comparison between meteorological aspects of model work and results obtained from surface measurements. This technique was restricted to describing quantitatively the perimeter of the fallout, the axis of the "hot line," and to determining the time of arrival of fallout throughout the pattern. No attempt was made to quantitate the expected levels of gamma activity or to develop radiation contour lines.

The task force employed a fallout prediction unit at this operation for determining the safe time to detonate the test devices. Many of their techniques for forecasting were similar to those described in this report, however, their problem was of a different nature than that of the fallout program. Several of their methods were unique in that portable analog computers were tested as field instruments. These computers permitted consideration of many complex parameters. One, in particular, obtained essentially an instantaneous solution to the problem once the meteorology was available.

The fallout program and the task force prediction unit functioned independently. It was not feasible for the two to employ the same technique because the postshot variability of the winds aloft were especially critical in ship-location problems in the fallout program. This problem will be discussed in detail later.

1.1 Objective

This report describes a technique of forecasting fallout employed at a recent weapons-test operation. The results obtained in the field are discussed as examples of the reliability of the techniques. Although the technique was designed for analysis of land surface detonations where the fallout is particulate, its application to water surface detonations is considered.

2. FORECASTING TECHNIQUE

The forecasting technique uses many ideas from fallout model work. Several simplifications as well as a plotting device have been developed to the end that the time involved has been reduced greatly without sacrificing accuracy. In general, an initial source of activity is defined describing the "stabilized" nuclear cloud by appropriate spatial and size distributions of radioactive particles. These particles are tracked to the earth's surface by considering their falling speeds and effects of the winds existing aloft.

2.1 Basic considerations

In some cases the input parameters for the forecasting technique were obtained from weapon-test measurements. In others where data were lacking, the parameters were derived from theory.

2.1.1 Source model

The optical or visible dimensions of the initial cloud from a nuclear detonation have been documented in past weapons tests. Available data describe such parameters as height to base of mushroom, height to top of mushroom, and mushroom diameter all as functions of time. Vertical rise stabilizes in approximately 6 min post detonation. This time is independent of yield, however, the expansion of the mushroom diameter particularly for the megaton devices continues for perhaps 30 min. Available diameter measurements have not been made in excess of H+10 min, however, fairly reliable data are known for the optical cloud dimensions as functions of yield to H+10 min. The ultimate cloud diameter can be extrapolated from low-yield curves and some qualitative data. Figures 1 and 2 present values of the cloud dimensions from past tests. The source model was assumed cylindrical having, for a given yield, these dimensions. Its stem diameter was taken as 10 percent of mushroom diameter.

2.1.2 Activity distribution in source model

The great part of the activity was assumed to be concentrated in the lower third of the mushroom. The lower two-thirds of the stem was ignored; the remainder of the stem and upper two-thirds of the cloud were weighted lightly. This description (fig. 3) of the activity distribution within the cloud appeared most reasonable in the light of available data and logical theoretical considerations. The activity was concentrated nearer the axis of symmetry of the cloud than at its outer edges.

2.1.3 Particle size distribution in source model

All particle sizes were assumed at all elevations within the cloud except the lower two-thirds of the stem. However, to obtain agreement with past fallout measurements and with the optical diameter of the mushroom, it was necessary to fractionate the particle size distribution radially within the cloud. Otherwise, the computed fallout area about ground zero would be too large. The fractionation was specified as follows: particles of 1,000 microns in diameter and larger were restricted to the inner 10 percent of the mushroom radius or approximately the stem radius; those from 500 to 1,000 microns in diameter were limited to the inner 50 percent of the cloud radius. Since the relation of activity to particle size is some function of the particle diameter this fractionation tends to concentrate the activity about the axis of symmetry of the cloud.

2.1.4 Particle falling speeds or settling rates

Computations of the terminal velocities of the particles were based on aerodynamic considerations for a still atmosphere having temperature and density distributions typical of the Marshall Islands atmosphere in the spring months.

Experimental data from past tests at Eniwetok Atoll indicated that the particles were irregular in shape and had a mean density of 2.36 g/cu cm.

It can be shown that particles falling at their terminal speed experience three types of flow in a fluid: streamline or laminar flow where viscous forces predominate, $(10^{-4} \leqq R_e \leqq 2.0)$; intermediate flow where inertia forces predominate, $(2 \leqq R_e \leqq 500)$; turbulent flow where inertia forces predominate, $(500 \leqq R_e \leqq 10^5)$. Below a Reynolds number of 10^{-4} certain corrections must be applied to the equations because the particle diameter approaches the mean free path of the fluid medium; the region above a Reynolds number of 10^5 is important only in ballistics. These limiting cases will not be discussed here.

The parameters actively affecting a particle's falling speed are: its weight, its drag coefficient, its density, as well as the fluid density and fluid viscosity.

Most empirical equations developed in past experimental work have been for spheres dropped in various liquids. Some work has been done on irregular shaped particles and some done in wind tunnels. The equations [1] used to determine the falling rates for particles in a fluid medium follow.

For Streamline motion, $10^{-4} \leqq R_e \leqq 2.0$

$$V_s = K_s \left(\frac{\rho - \rho_o}{\rho_o}\right) (d^2) \left(\frac{\mu}{\rho_o}\right)^{-1} \qquad (1)$$

where

V_s = terminal velocity in cm/sec
ρ = particle density in gms/cm^3
ρ_o = fluid density in gms/cm^3
d = particle diameter in cm
μ = absolute viscosity of fluid in poises
K_s = constant incorporating gravity
= 54.5 for spheres
= 36.0 for irregular shaped particles.

The limiting diameter to which Eq. 1 holds is

$$d' = \left(\frac{36\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for spheres and

$$d' = \left(\frac{54.4\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for irregular shaped particles.

[1] J. M. Dallavalle, Mircomeritics, Pittman Publishing Corp., 1948.

For Intermediate motion, $2.0 \leqq R_e \leqq 500$

$$V_I = K_I \left(\frac{\rho - \rho_o}{\rho_o}\right)^{2/3} \left(\frac{\mu}{\rho_o}\right)^{-1/3} d_o \qquad (2)^2$$

where $d_o = d - \xi d'$
$\xi = 0.4$ for spheres
$\xi = 0.279$ for irregular shapes
d' = limiting diameter to which streamline motion applies
$K_I = 30.0$ for spheres
$= 19.0$ for irregular shapes.

The limiting diameter to which the Eq. 2 holds is

$$d'' = 43.5 \left(\frac{\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for spheres

$$d'' = 51 \left(\frac{\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for irregular shapes.

For Turbulent motion, $500 \leqq R_e \leqq 10^5$

$$V_T = K_T \left[\left(\frac{\rho - \rho_o}{\rho_o}\right) d\right]^{1/2} \qquad (3)^2$$

$K_T = 54.6$ for spheres
$= 50.0$ for irregular particles.

The question of particle diameter becomes puzzling when the equations are applied to irregular shaped particles. Although the equations for irregular shaped particles cannot be applied to an individual particle, they are assumed valid in establishing the average falling rates of many irregular particles clustered about this defined size.

2.1.5 Marshall Islands atmosphere

Marshall Islands atmospheric conditions determined the values for the density and viscosity parameters used in computing particle falling rates. Available data on the temperature, pressure, density, and viscosity as functions of altitude for the atmosphere common to the Marshall Island area in the spring months follow.

It was not possible to use a "standard atmosphere" in this problem because such use introduced a large error in the particle falling rate at high altitudes. This error originates primarily because of the assumed isothermal layer above the tropopause.

2.1.5.1 Temperature distribution

From the weather data published by Task Force Weather Central at Operation Castle, four published radiosonde runs obtained temperature measurements to high altitudes:

March 1, 1954, 0600 M Bikini
March 27, 1954, 0600 M Bikini
April 7, 1954, 0620 M Bikini
April 26, 1954, 0610 M Bikini

No data were available above 67,000 feet. Fortunately two of these runs penetrated the tropopause which was located at approximately 55,000 feet. To extend the measured data beyond 67,000 feet climatological averages [3] for latitude 12° North were employed. Agreement with measured data was satisfactory except for the range from 50,000 to 65,000 feet where the climatological data indicated a well-defined isothermal layer. The most significant finding from the measured data was the complete lack of an isothermal layer above the tropopause. Instead, a distinct and rapid inversion was observed which when extrapolated as a straight line agreed with the climatological data above 70,000 feet. Since the atmosphere was to be defined to 120,000 feet further extrapolation was necessary. The only temperature data available at these higher altitudes were taken by rockets [4] over White Sands, N. Mex. A plot of 3 points from the rocket data justifies to some extent a continued extrapolation of the curve to 120,000 feet.

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[2] These equations were taken from reference 1; however, certain constants have been reevaluated.
[3] Brunt, David, Physical and Dynamical Meteorology, the University Press, 1941.
[4] Chief of Naval Operations, A Study of the Atmosphere Between 30,000 and 100,000 Feet (preliminary report), September 1948.

2.1.5.4 Viscosity distribution

The variation of absolute viscosity with altitude was computed from the observed temperature distribution using Sutherland's formula,[6]

$$\mu = u_o \left(\frac{T_0+114}{T+114}\right)\left(\frac{T}{T_o}\right)^{3/2}$$

$$u = 0.01709 \left(\frac{387.17}{t_i+114}\right)\left(\frac{t_i}{273.17}\right)^{3/2}$$

where t_i equals temperature in degrees Kelvin and μ is viscosity in centipoises. These data are plotted in figure 7.

The data on pressure, temperature, density, and viscosity in 1,000-foot intervals to 120,000 feet are summarized in table 1.[7]

TABLE 1.—*Table of temperature, pressure, density, and viscoscity of the atmosphere over the Marshall Islands during the spring*

Altitude (feet)	Temperature ° K	Pressure (Mb)	Density (g/cm^3·10^3)	Viscosity (poises·10^4)
SFC	300	1,006	1.17	1.84
1,000	299	980	1.13	1.83
2,000	297	950	1.10	1.825
3,000	296	930	1.06	1.815
4,000	295	900	1.03	1.810
5,000	293	870	1.0	1.805
6,000	292	850	.97	1.795
7,000	290	820	.94	1.785
8,000	289	800	.91	1.780
9,000	288	770	.88	1.770
10,000	285	740	.86	1.765
11,000	284	720	.83	1.775
12,000	282	690	.80	1.745
13,000	280	660	.78	1.740
14,000	278	640	.76	1.730
15,000	276	620	.73	1.720
16,000	274	590	.71	1.715
17,000	273	570	.69	1.705
18,000	271	550	.67	1.695
19,000	269	530	.65	1.685
20,000	267	500	.63	1.675
21,000	265	480	.61	1.665
22,000	263	460	.59	1.655
23,000	261	440	.57	1.645
24,000	259	420	.55	1.635
25,000	257	410	.53	1.625
26,000	255	390	.52	1.615
27,000	252	370	.50	1.600
28,000	250	355	.49	1.590
29,000	248	340	.47	1.580
30,000	246	320	.45	1.570
31,000	243	310	.43	1.560
32,000	241	300	.42	1.545
33,000	239	280	.41	1.535
34,000	236	270	.39	1.525
35,000	234	260	.38	1.510
36,000	232	245	.37	1.500
37,000	230	235	.36	1.490
38,000	227	225	.35	1.475
39,000	225	215	.33	1.465
40,000	223	205	.32	1.450
41,000	220	195	.31	1.440
42,000	218	185	.30	1.430
43,000	215	175	.29	1.420
44,000	213	165	.28	1.405
45,000	211	160	.27	1.395
46,000	209	150	.26	1.380
47,000	206	145	.25	1.370
48,000	204	135	.24	1.355
49,000	201	130	.23	1.345
50,000	199	125	.22	1.335
51,000	196	115	.21	1.320
52,000	194	110	.20	1.310
53,000	193	105	.19	1.295
54,000	192	100	.18	1.285

[6] Smithsonian Physical Tables, 1954.

[7] A great deal of excellent upper air data for the Marshall Islands was obtained at Operation Redwing in 1956. Reduction of these data will result in a much better description of the Marshall Islands atmosphere than has been previously available.

TABLE 1.—*Table of temperature, pressure, density, and viscosity of the atmosphere over the Marshall Islands during the spring*—Continued

Altitude (feet)	Temperature °K	Pressure (Mb)	Density ($g/cm^3 \cdot 10^3$)	Viscosity (poises·10^4)
55,000	191	95	.17	1.275
56,000	191	90	.16	1.275
57,000	192	85	.155	1.280
58,000	193	80	.145	1.290
59,000	194	77	.14	1.295
60,000	195	73	.135	1.300
61,000	197	70	.125	1.310
62,000	198	66	.115	1.320
63,000	199	63	.110	1.325
64,000	201	60	.105	1.330
65,000	202	56	.10	1.340
66,000	203	53	.094	1.345
67,000	205	50	.088	1.350
68,000	206	48	.083	1.360
69,000	207	46	.078	1.365
70,000	208	43	.073	1.370
71,000	210	41	.070	1.380
72,000	211	39	.066	1.385
73,000	213	37	.062	1.395
74,000	214	35	.058	1.400
75,000	215	33	.054	1.405
76,000	217	32	.052	1.415
77,000	218	30	.049	1.420
78,000	219	28	.046	1.430
79,000	221	27	.044	1.435
80,000	222	26	.042	1.440
81,000	223	24	.039	1.450
82,000	225	23	.037	1.455
83,000	226	22	.034	1.465
84,000	227	21	.032	1.470
85,000	229	20	.030	1.480
86,000	230	19	.029	1.485
87,000	231	18	.027	1.490
88,000	233	17	.026	1.500
89,000	234	16	.024	1.505
90,000	235	15	.023	1.510
91,000	237	14.5	.0215	1.520
92,000	238	14	.0205	1.525
93,000	239	13	.019	1.535
94,000	241	12.5	.018	1.540
95,000	242	12	.017	1.550
96,000	243	11	.016	1.555
97,000	245	10.5	.015	1.565
98,000	246	10	.014	1.570
99,000	247	9.5	.0135	1.575
100,000	249	9	.0130	1.585
101,000	250	8.5	.0102	1.590
102,000	251	8	.01015	1.600
103,000	253	7.6	.0105	1.605
104,000	254	7.4	.010	1.610
105,000	255	7.0	.0095	1.620
106,000	257	6.6	.0090	1.625
107,000	258	6.2	.0085	1.635
108,000	259	6.0	.0080	1.640
109,000	261	5.6	.0075	1.650
110,000	262	5.4	.0070	1.655
111,000	263	5.1	.0068	1.660
112,000	265	4.9	.0064	1.670
113,000	266	4.6	.0060	1.675
114,000	267	4.4	.0056	1.685
115,000	269	4.2	.0054	1.690
116,000	270	3.9	.0050	1.700
117,000	271	3.7	.0048	1.705
118,000	273	3.6	.0044	1.710
119,000	274	3.4	.0042	1.720
120,000	275	3.2	.0040	1.725

2.1.5.5 Terminal velocity computations

The average falling speed through 5,000-foot layers was computed for 4 particle sizes over an altitude range from 0 to 120,000 feet. In these computations all in-flight transition of the particles from streamline to intermediate flow had to be considered through use of the plot shown in figure 8.

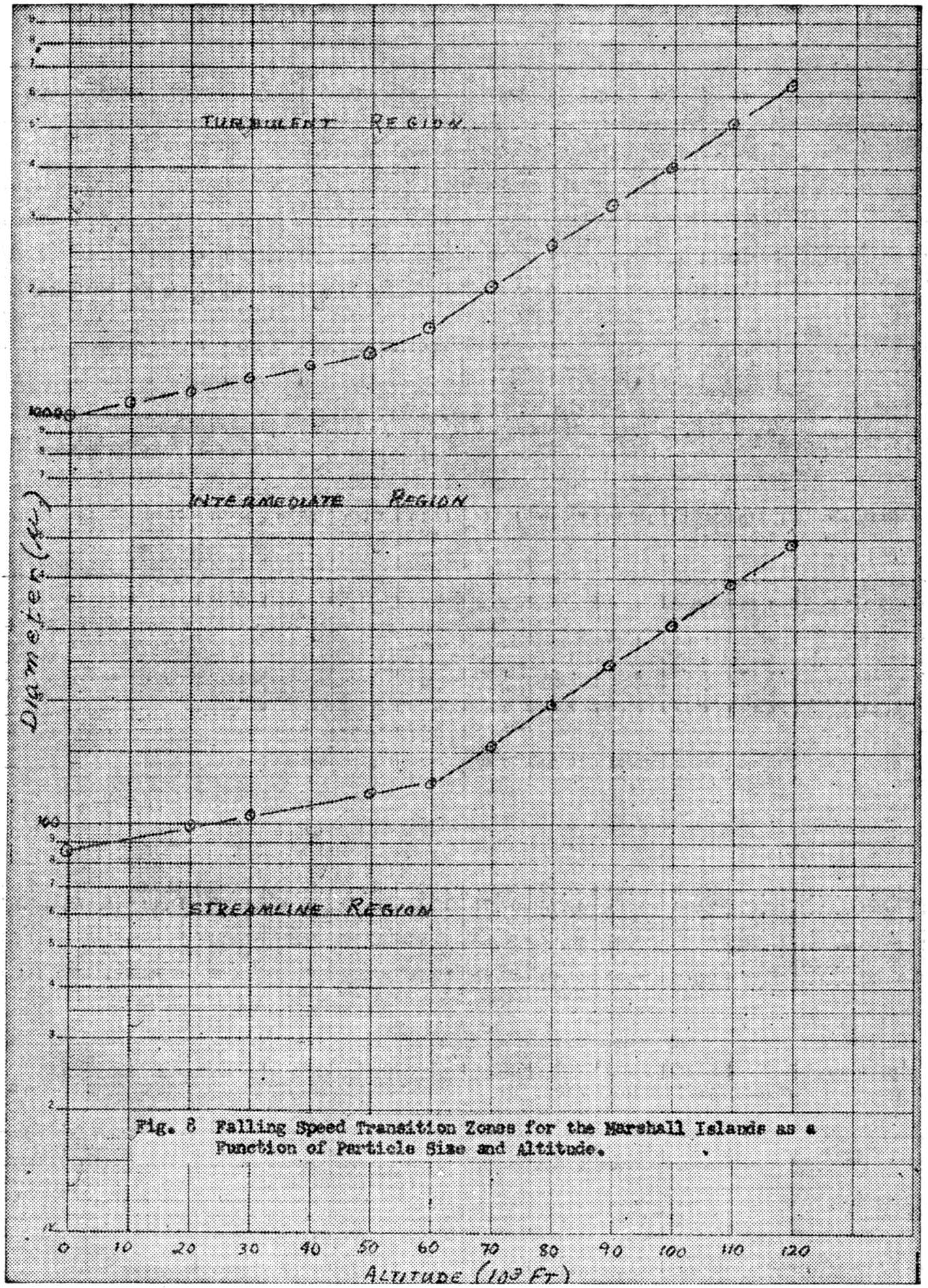

Fig. 8 Falling Speed Transition Zones for the Marshall Islands as a Function of Particle Size and Altitude.

Four particle sizes (75 μ, 100 μ, 200 μ, and 350 μ diameter) were employed since there was evidence from past tests that the 75 μ particle defined the limiting distance of fallout of interest and the larger sizes best described the pattern wihin this limit. Table 2 presents the falling speeds computed for the 4 sizes. Tables 3, 4, 5, and 6 display the cumulative time of fall from a given altitude for these particle diameters.

TABLE 2.—*Falling speeds as a function of altitude*

[Falling speeds (foot-hour)]

Altitude	75	100	200	350	Altitude	75	100	200	350
0	3,060	5,040	11,700	21,600	65	4,190	7,480	26,100	51,100
5	3,120	5,240	12,300	22,900	70	4,110	7,320	27,600	55,200
10	3,200	5,480	12,900	24,100	75	4,010	7,150	28,100	59,700
15	3,270	5,750	13,700	25,500	80	3,910	6,960	27,800	61,900
20	3,360	5,980	14,400	27,100	85	3,800	6,770	27,100	67,800
25	3,470	6,160	15,300	28,800	90	3,720	6,640	26,500	71,300
30	3,570	6,380	16,300	30,800	95	3,620	6,470	25,800	77,300
35	3,720	6,640	17,500	33,000	100	3,550	6,340	25,300	80,200
40	3,870	6,910	18,600	35,300	105	3,470	6,180	24,800	75,800
45	4,040	7,200	19,800	37,800	110	3,400	6,050	24,000	74,200
50	4,210	7,520	21,400	40,600	115	3,330	5,930	23,700	72,600
55	4,420	7,860	23,200	44,600	120	3,260	5,800	23,400	71,100
60	4,200	7,700	24,400	47,200					

TABLE 3.—*Cumulative time of fall for the 75-μ particles*

[Cumulative time of fall (hours)]

Starting elevation feet 10^{-3}	120 to 115	115 to 110	110 to 105	105 to 100	100 to 95	95 to 90	90 to 85	85 to 80	80 to 75	75 to 70	70 to 65	65 to 60
120 to 115	1.52											
115 to 110	3.01	1.49										
110 to 105	4.46	2.94	1.45									
105 to 100	5.88	4.36	2.87	1.42								
100 to 95	7.27	5.75	4.26	2.81	1.39							
95 to 90	8.63	7.11	5.62	4.17	2.75	1.36						
90 to 85	9.96	8.44	6.95	5.50	4.08	2.69	1.33					
85 to 80	11.26	9.74	8.25	6.80	5.38	3.99	2.63	1.30				
80 to 75	12.52	11.00	9.51	8.06	6.64	5.25	3.89	2.56	1.26			
75 to 70	13.75	12.23	10.74	9.29	7.87	6.48	5.12	3.79	2.49	1.23		
70 to 65	14.95	13.43	11.94	10.49	9.07	7.68	6.32	4.99	3.69	2.43	1.20	
65 to 60	16.14	14.62	13.13	11.68	10.26	8.87	7.51	6.18	4.88	3.62	2.39	1.19
60 to 55	17.30	15.78	14.29	12.84	11.42	10.03	8.67	7.34	6.04	4.78	3.55	2.35
55 to 50	18.46	16.94	15.45	14.00	12.58	11.19	9.83	8.50	7.20	5.94	4.71	3.51
50 to 45	19.67	18.15	16.66	15.21	13.79	12.40	11.04	9.71	8.41	7.15	5.92	4.72
45 to 40	20.93	19.41	17.92	16.47	15.05	13.66	12.30	10.97	9.67	8.41	7.18	5.98
40 to 35	22.25	20.73	19.24	17.79	16.37	14.98	13.62	12.29	10.99	9.73	8.50	7.30
35 to 30	23.62	22.10	20.61	19.16	17.74	16.35	14.99	13.66	12.36	11.10	9.87	8.67
30 to 25	25.04	23.52	22.03	20.58	19.16	17.77	16.41	15.08	13.78	12.52	11.29	10.09
25 to 20	26.50	24.98	23.49	22.04	20.62	19.23	17.87	16.54	15.24	13.98	12.75	11.55
20 to 15	28.01	26.49	25.00	23.55	22.13	20.74	19.38	18.05	16.75	15.49	14.26	13.06
15 to 10	29.55	28.03	26.54	25.09	23.67	22.28	20.92	19.59	18.29	17.03	15.80	14.60
10 to 5	31.13	29.61	28.12	26.67	25.25	23.86	22.50	21.17	19.87	18.61	17.38	16.18
5 to 0	32.75	31.23	29.74	28.29	26.87	25.48	24.12	22.79	21.49	20.23	19.00	17.80

Starting elevation feet 10^{-3}	60 to 55	55 to 50	50 to 45	45 to 40	40 to 35	35 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to 5	5 to 0
120 to 115												
115 to 110												
110 to 105												
105 to 100												
100 to 95												
95 to 90												
90 to 85												
85 to 80												
80 to 75												
75 to 70												
70 to 65												
65 to 60												
60 to 55	1.16											
55 to 50	2.32	1.16										
50 to 45	3.53	2.37	1.21									
45 to 40	4.79	3.63	2.47	1.26								
40 to 35	6.11	4.95	3.79	2.58	1.32							
35 to 30	7.48	6.32	5.16	3.95	2.69	1.37						
30 to 25	8.90	7.74	6.58	5.37	4.11	2.79	1.42					
25 to 20	10.36	9.20	8.04	6.83	5.57	4.25	2.88	1.46				
20 to 15	11.87	10.71	9.55	8.34	7.08	5.76	4.39	2.97	1.51			
15 to 10	13.41	12.25	11.09	9.88	8.62	7.30	5.93	4.51	3.05	1.54		
10 to 5	14.99	13.83	12.67	11.46	10.20	8.88	7.51	6.09	4.63	3.12	1.58	
5 to 0	16.61	15.45	14.29	13.08	11.82	10.52	9.13	7.71	6.25	4.74	3.20	1.62

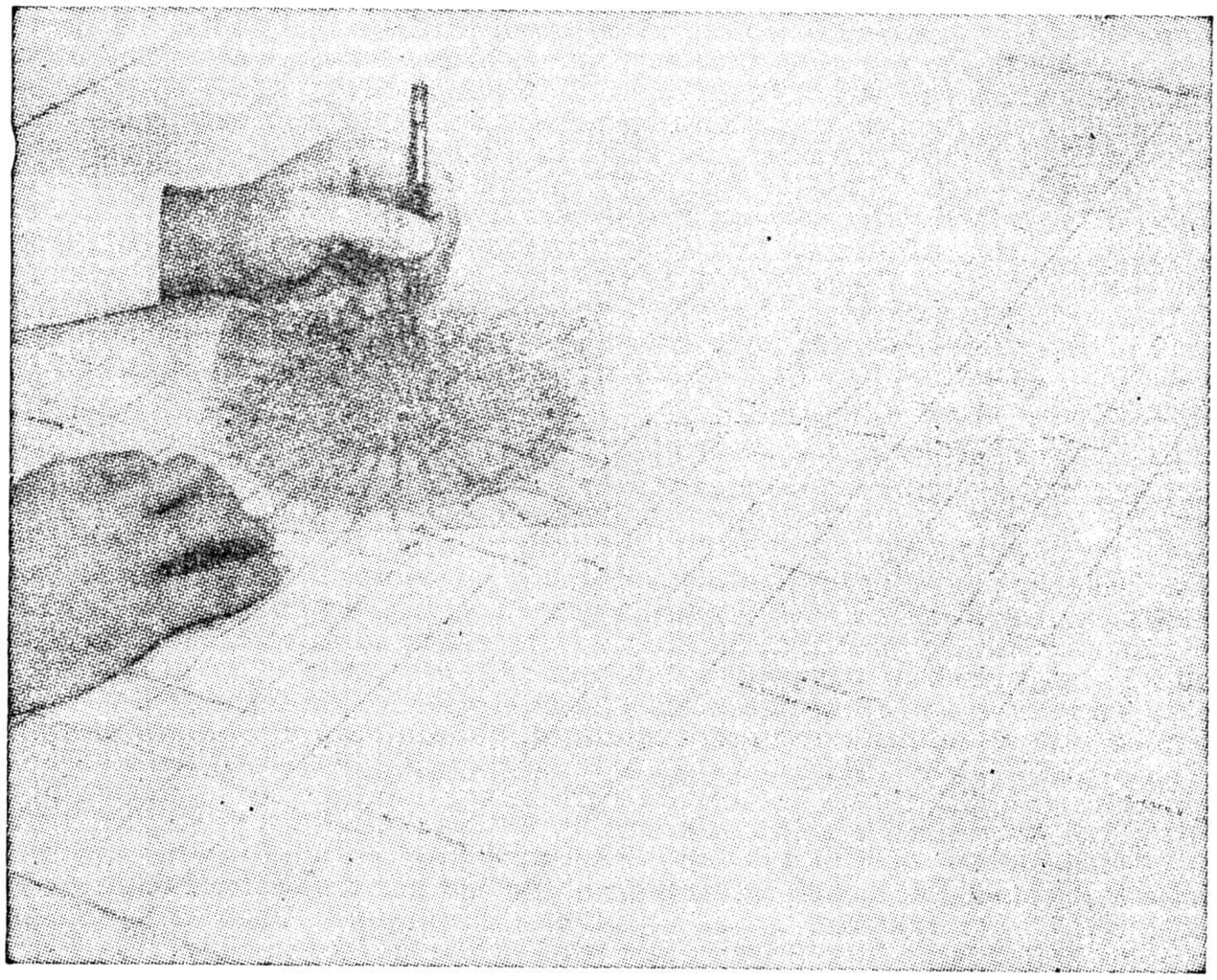

FIGURE 11.—Fallout plotting device.

A plotting device (fig. 11) has been described elsewhere[8] which facilitates the computations required for the size lines of the fallout pattern. Such devices were constructed for 4 particle sizes: 75, 100, 200, and 350 μ in diameter. With these plotters trajectories or size lines can be plotted from any elevation to 120,000 feet for the 4 particle sizes. The plotters automatically account for the variable particle falling speed. They also eliminate the need for drafting equipment. After establishing the particle arrival points by either the use of size lines or trajectories, height lines can be constructed. These lines joining surface zero with the arrival points of all particles from the same elevation are most descriptive for they define the path along which all particle sizes will deposit from that originating altitude.

The height lines describing the fallout from the lower portion of the mushroom immediately establish the "hot line." The "hot line" is best defined as that portion of the fallout area wherein the highest levels of activity are found relative to the adjacent areas. Under most meteorological conditions this area is described by a line from surface zero that coincides with the height lines from the altitude layers that include the base of the mushroom; for the source model was so defined to concentrate the activity in this volume.

Since the plotted grid of size lines and height lines was based on a line source of activity each particle point must be expanded to the appropriate cloud or stem diameter from which it originated. This expansion, after taking into consideration the radial particle size fractionation in the source model, defines the perimeter of the area. One then has a map indicating the fallout area and the path of expected highest activity.

Curves of time of arrival of fallout through the pattern are established by simply assigning the appropriate value of falling time to each expanded circle about the arrival points and by constructing from this network of values isotime contours that indicate the earliest time at which fallout will arrive at a given distance from the shot point. The determination of the time of cessation of fallout at any location may be plotted similarly, however, one is faced with the

[8] E. A. Schuert, A Fallout Plotting Device, USNRDL Technical Rept. 127, February 1957.

question of how to define cessation. Very small particles that do not contribute significantly to the radiation field continue to arrive for days after time zero. Consequently, a plot which describes time to peak activity seems more meaningful. During the field operation time to peak activity was defined as the time of arrival of fallout particles originating in the lower third of the mushroom.

This method determines the fallout plot under conditions that do not involve several important meteorological variables. It is most valid for a fallout of short duration and over a relatively small area, for example, a 1-kiloton surface detonation. Megaton devices and large kiloton yields deposit primary fallout over long periods and to great distances. To map such extensive deposition of fallout necessitates inclusion of complex meteorological variables and consideration of the fact that clouds from these large detonations extend to great heights in the atmosphere.

2.2.1 Time variation of the winds aloft

In most of the observations made at the Eniwetok Proving Ground, the winds aloft were not in a steady state. Significant changes in the winds aloft were observed in as short a period as 3 hours. This variability was probably due to the fact that proper firing conditions which required winds that would deposit the fallout north of the proving ground, occurred only during an unstable synoptic situation of rather short duration. It was necessary to correct for this variation to keep track of the predicted fallout area, especially at great distances from surface zero where as much as 20 hours elapsed before deposition.

Since this variation could not be forecast, balloon runs were made every 3 hours from H+O to H+24 and each particle trajectory employed the winds as they changed with time. The correct particle trajectories were approached by a method of successive approximations as follows: Tables 3 through 6 were computed for the four particle sizes and gave their cumulative times of fall such that starting at any elevation their altitude at any time after H-hour could be located. For example, the 75-μ particle originating at 70,000 feet entered the 40,000-foot layer in 7.18 hours and reached the surface in 19 hours. Since new upper air observations were obtained every 3 hours it was assumed that the balloon released at H+O represented the winds aloft until H+3 hours and the balloon released at H+3 hours represented the winds until H+6 hours and so on. Therefore, as the particle settled to earth the appropriate winds aloft were applied to it.

The first step was to plot size lines for the particles based on the H+O hour winds. This established a fallout plot that assumed the winds would not change with time. When the H+3 winds became available a similar plot was made based on them. With the aid of tables 3 through 6 the particles starting at various elevations were located in altitude at H+3. These H+3 hour points are marked at the proper altitude on each size line. The two size lines, H+O and H+3 are then overlayed such that the H+3 hour points are conicident and the combined size lines determined with the aid of a light table. This is done by taking the upper portion of the H+O hour size line and the lower portion of the H+3 size line. This first approximation then assumes that the H+3 hour winds will remain steady for the remainder of the particles flight. The process is repeated using the combined size line and the new size line for the next set of wind data until the particle reaches the surface. Therefore for each new wind observation a closer approximation of the corrected time variable plot is made until ultimately the plot is quantitative.

2.2.2 Space variation

The preceding computations assumed that the winds aloft as measured at the point of detonation at a given time are the same throughout the area for that time. Since the fallout can deposit hundreds of miles from surface zero, ideally, one would like winds-aloft measurements throughout the volume traversed by the particles. Correction for space variation of the winds is then necessary, however, in most cases not as significant as is time variation. Most weather networks are not refined enough to allow quantitative correction for these errors.

2.2.3 Vertical motions

In applying particle falling speeds to the forecasting technique, it is assumed that the atmosphere has no vertical velocity. Computations made at the Eniwetok Proving Ground[9] to 50,000 feet indicated that large cellular vertical

[9] Under the direction of Comdr. Daniel F. Rex, Joint Task Force Seven Meteorological Center, Pearl Harbor, T. H.

motions in the atmosphere sometimes attained speeds equal to and greater than the settling speed of a 75-μ particle. A time-space correction should be made to the falling speeds of the particles to compensate for this parameter. However, in the work at the test site it was not possible to include this effect in the fallout forecasts. Certain anomalies discussed below may be due to such an effect and postshot analysis is being conducted to see whether they are resolved when the vertical motions have been taken into account.

3. DISCUSSION OF FIELD TEST RESULTS

The forecasting technique described was employed by the fallout program at the Eniwetok Proving Ground to satisfy certain project requirements. One project had three ships equipped to collect fallout and their positions had to be determined for most efficient collection; another sampled the ocean for fallout; while another made an aerial survey of the contaminated area. The navigational schedules for these latter projects were based on the forecast fallout pattern. Operations were controlled through the program control center aboard the task force command ship where the forecasts were prepared.

The meteorological data was received from the weather ship at Bikini Atoll as well as from weather stations at Rongerik Atoll and Eniwetok Atoll. Furthermore all forecasts made by the task force weather central at Eniwetok Atoll were usually available aboard the command ship by facsimile through the ships weather station.

Upper air measurements were made at Bikini, Rongerik, and Eniwetok Atolls every 3 hours starting at H—24 hour and continuing until H+24 hour for any given detonation. The frequency of observations was usually increased during the period from H—6 to H—2 hours. The altitudes reached on the wind runs were remarkably high and gave perhaps the best set of winds-aloft measurements to date. The average termination altitude was approximately 90,000 feet with many runs over 100,000 feet. Such excellent coverage of the winds aloft was a major help in the fallout forecasting.

Fallout forecasts were made every 3 hours starting at H—24 hour using the *measured* winds available at the time. This process was continued up to shot time and from then on the technique of correcting for time variation was employed every 3 hours until the fallout event was completed. It was not feasible to correct for space variation and vertical motions during this period because of lack of time and data.

3.1 Fallout plots

The fallout forecasts determined at the weapons-test operation were based entirely on measured data and quantitatively considered time variation of the wind. No space variation corrections or computed values of vertical motions were employed in their construction.

The area of measured fallout from shot A is compared with the forecast fallout plot in figure 12. Figures 13, 14, and 15 are similar comparisons for shots B, C, and D. Although C and D were water-surface shots, it is evident that the forecasting technique succeeded in representing the measured fallout area as well as it did for the land-surface detonations, A and B.

The comparison is excellent for all shots except B and as yet the discrepancy betwen the forecast fallout area and that which was measured is unknown. There is some indication that consideration of vertical motions will have to be made for shot B during the time of fallout since computed vertical motions were significant in magnitude. Such analysis including space variation is being carried out at this time for all four detonations and the refined data will be published later.

4. SUMMARY

The fallout forecasting technique described in this report was successfully employed for both land surface and water surface detonations at the Eniwetok Proving Ground. With known meterological data such a technique will successfully qualify the area of fallout and indicate qualitatively the relative intensity of radiation.

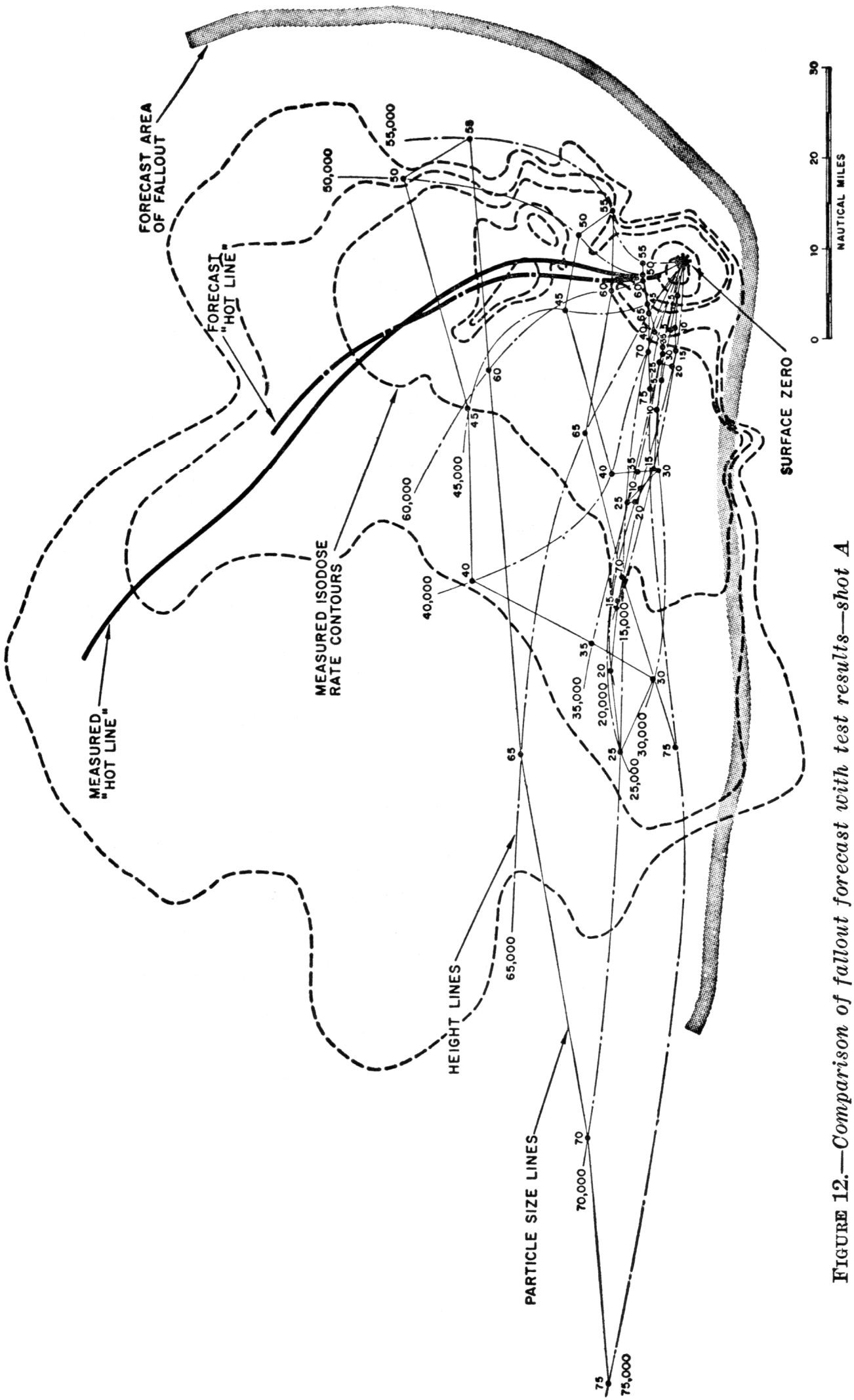

FIGURE 12.—*Comparison of fallout forecast with test results—shot A*

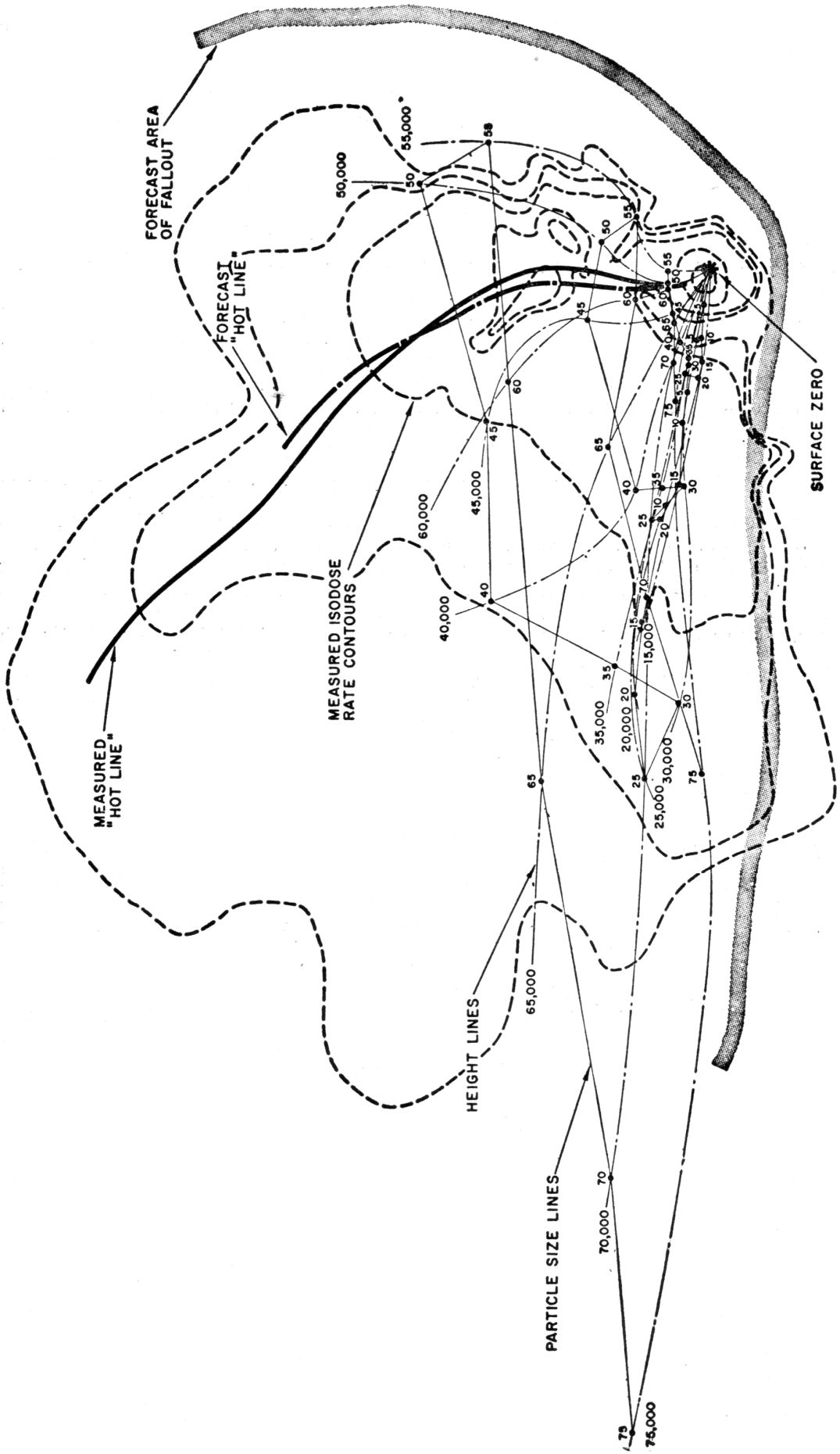

FIGURE 12.—*Comparison of fallout forecast with test results—shot A*

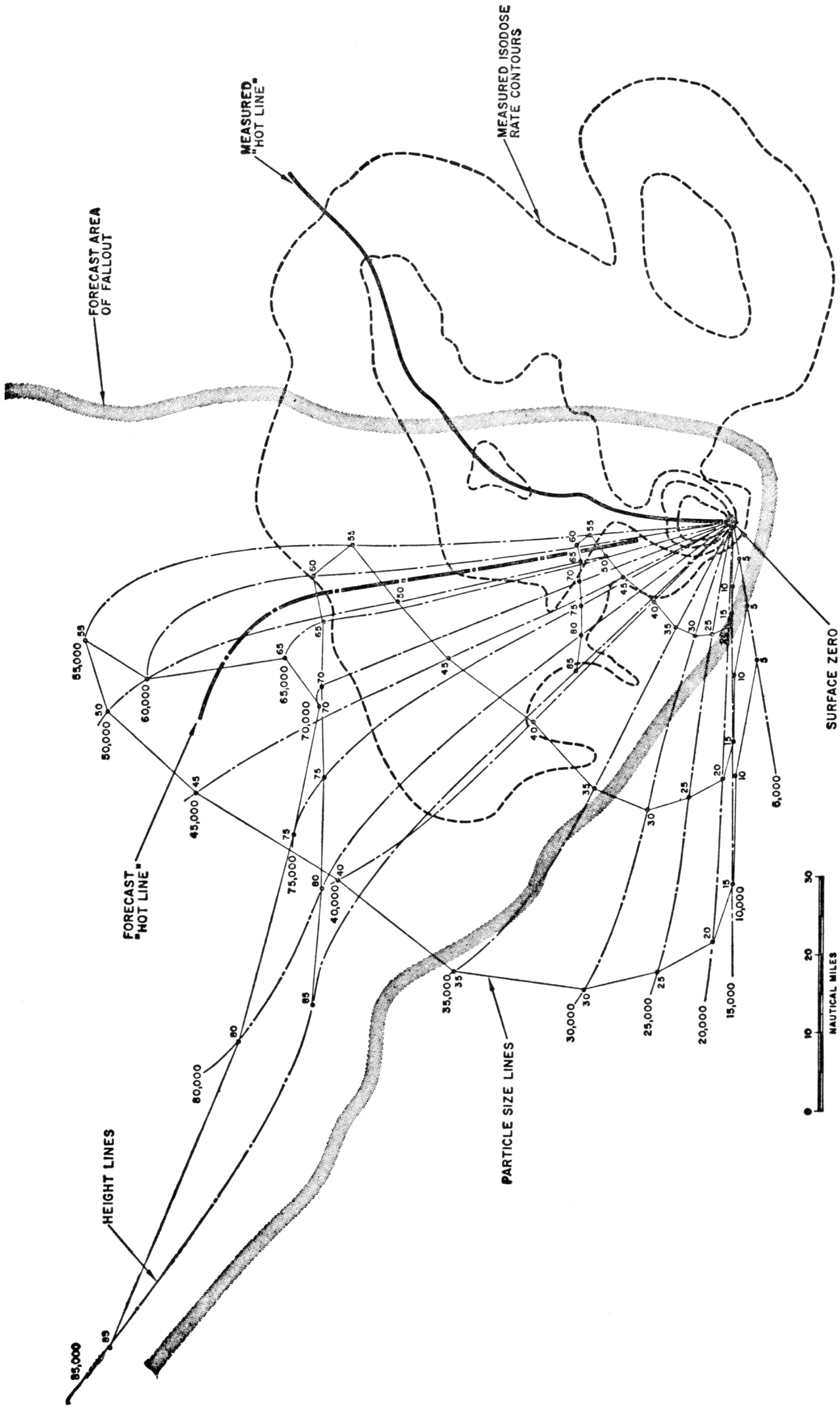

FIGURE 13.—*Comparison of fallout forecast with test results—shot B.*

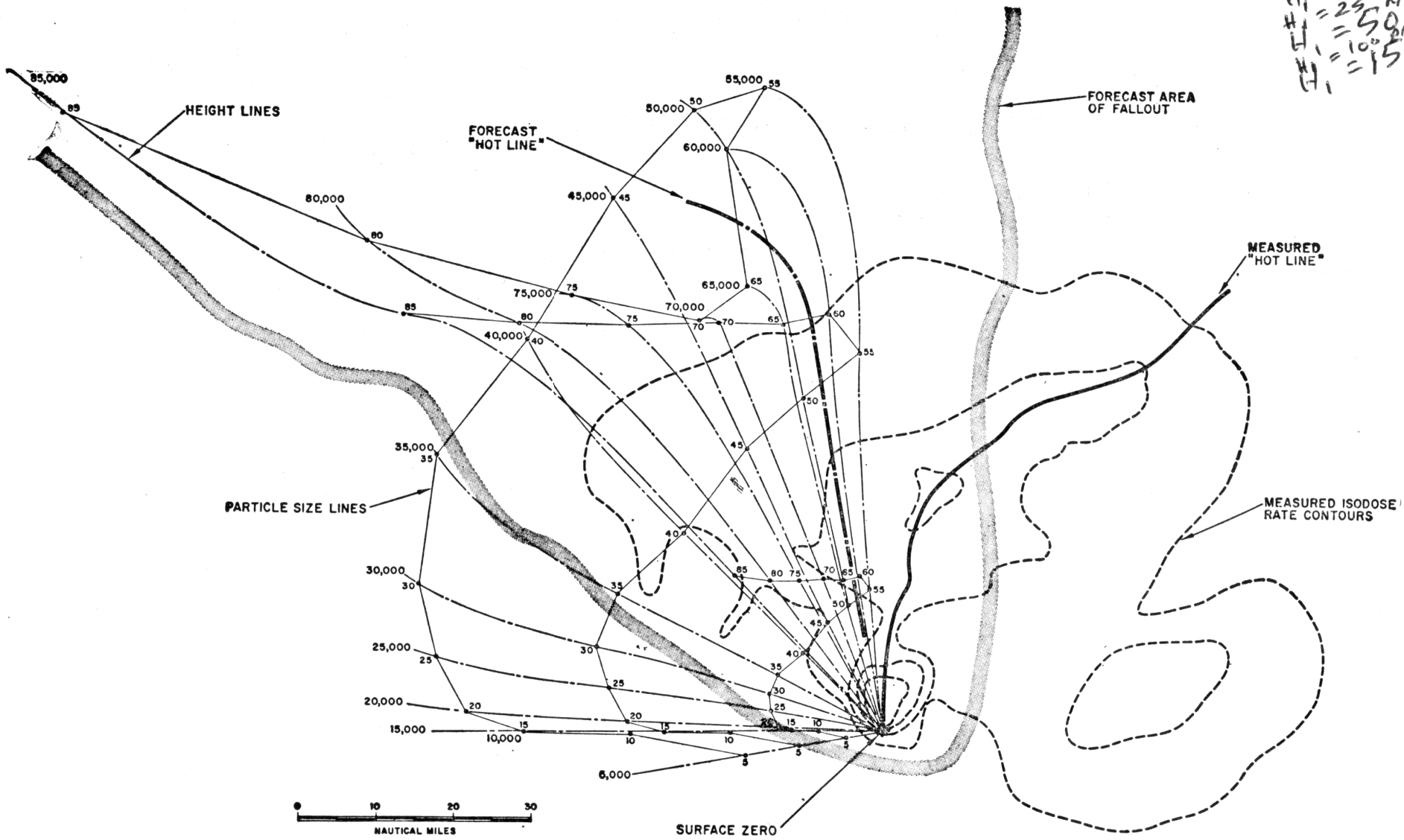

FIGURE 13.—*Comparison of fallout forecast with test results—shot B.*

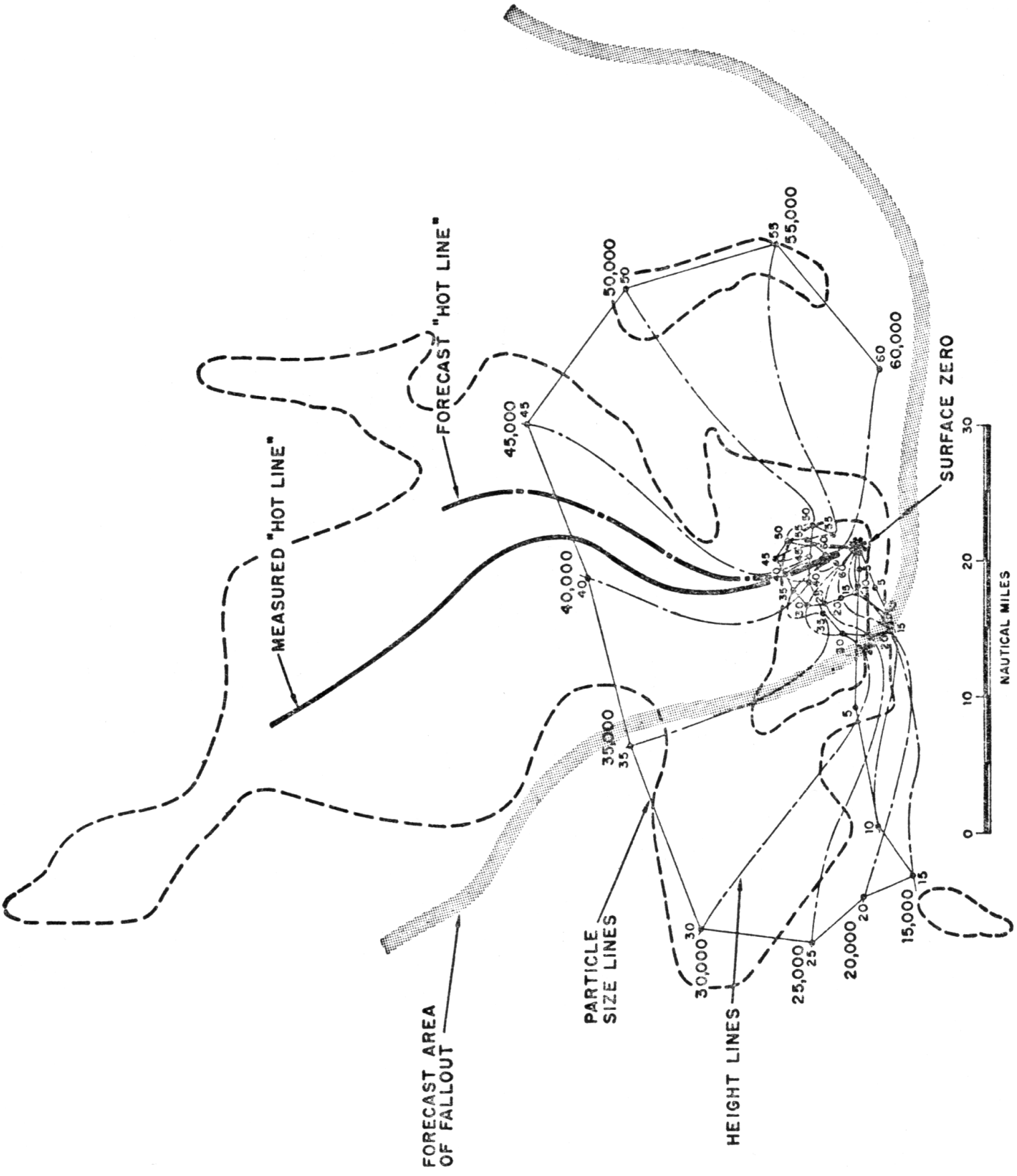

FIGURE 14.—*Comparison of fallout forecast with test results—shot C.*

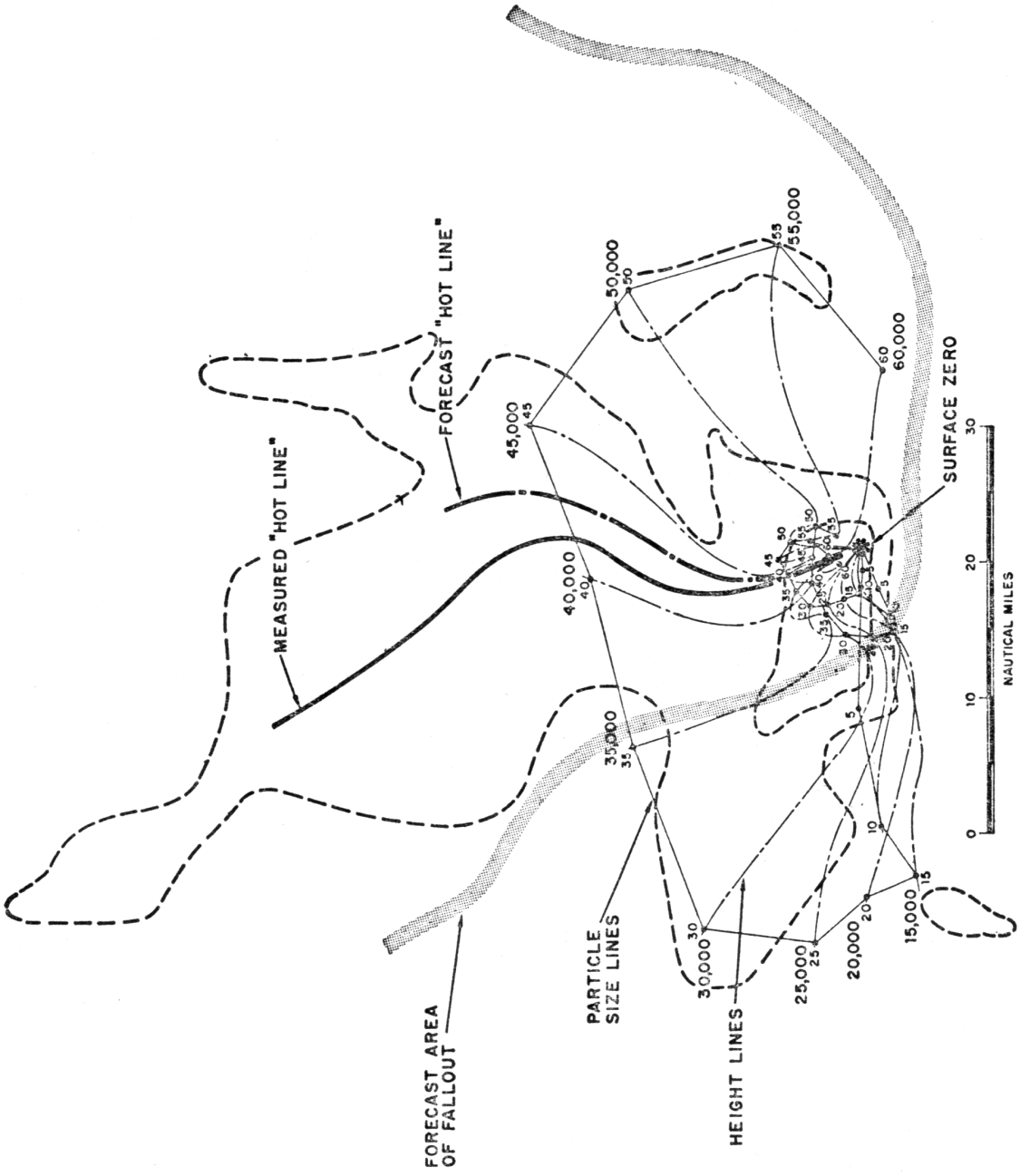

FIGURE 14.—*Comparison of fallout forecast with test results—shot C.*

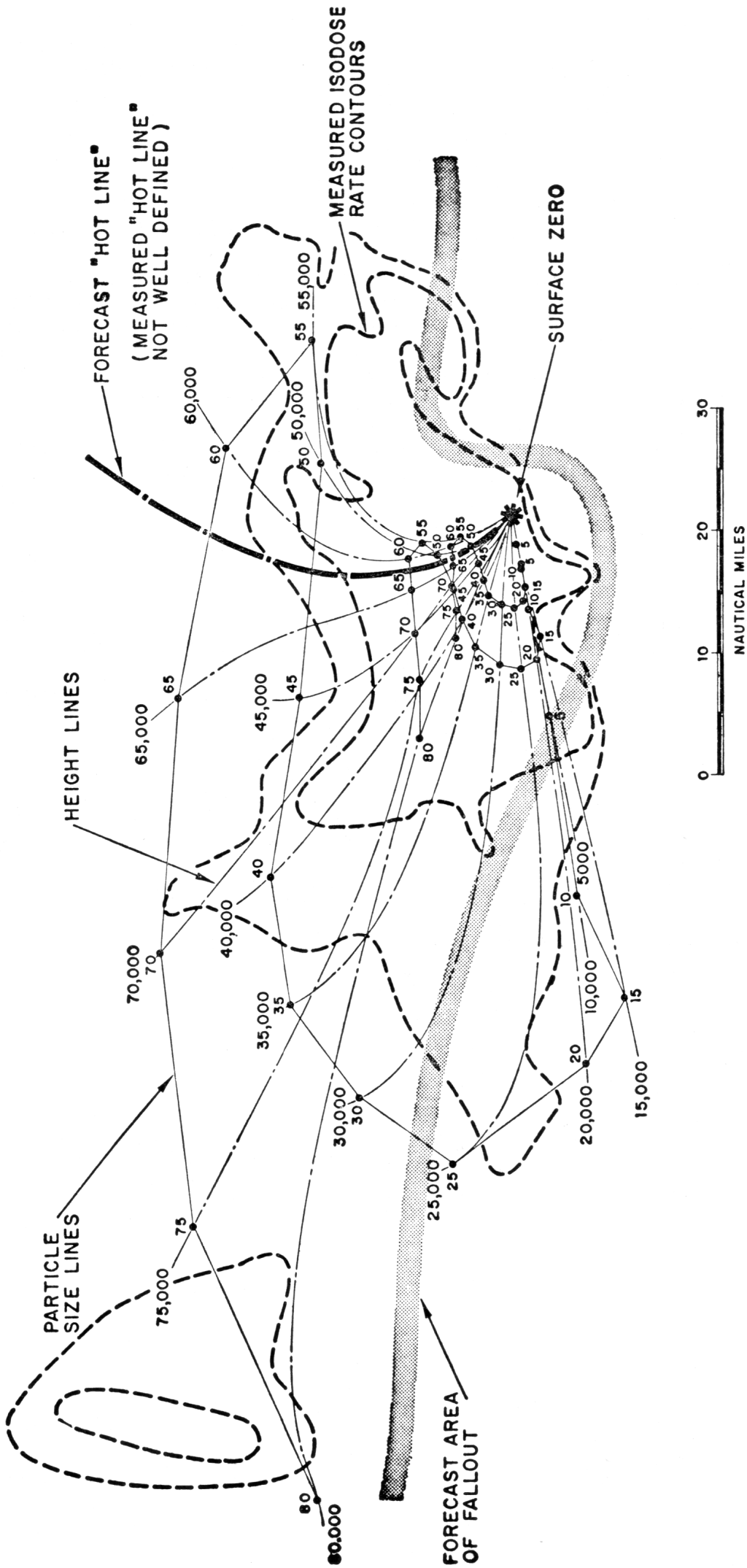

FIGURE 15.—*Comparison of fallout forecast with test results—shot D.*

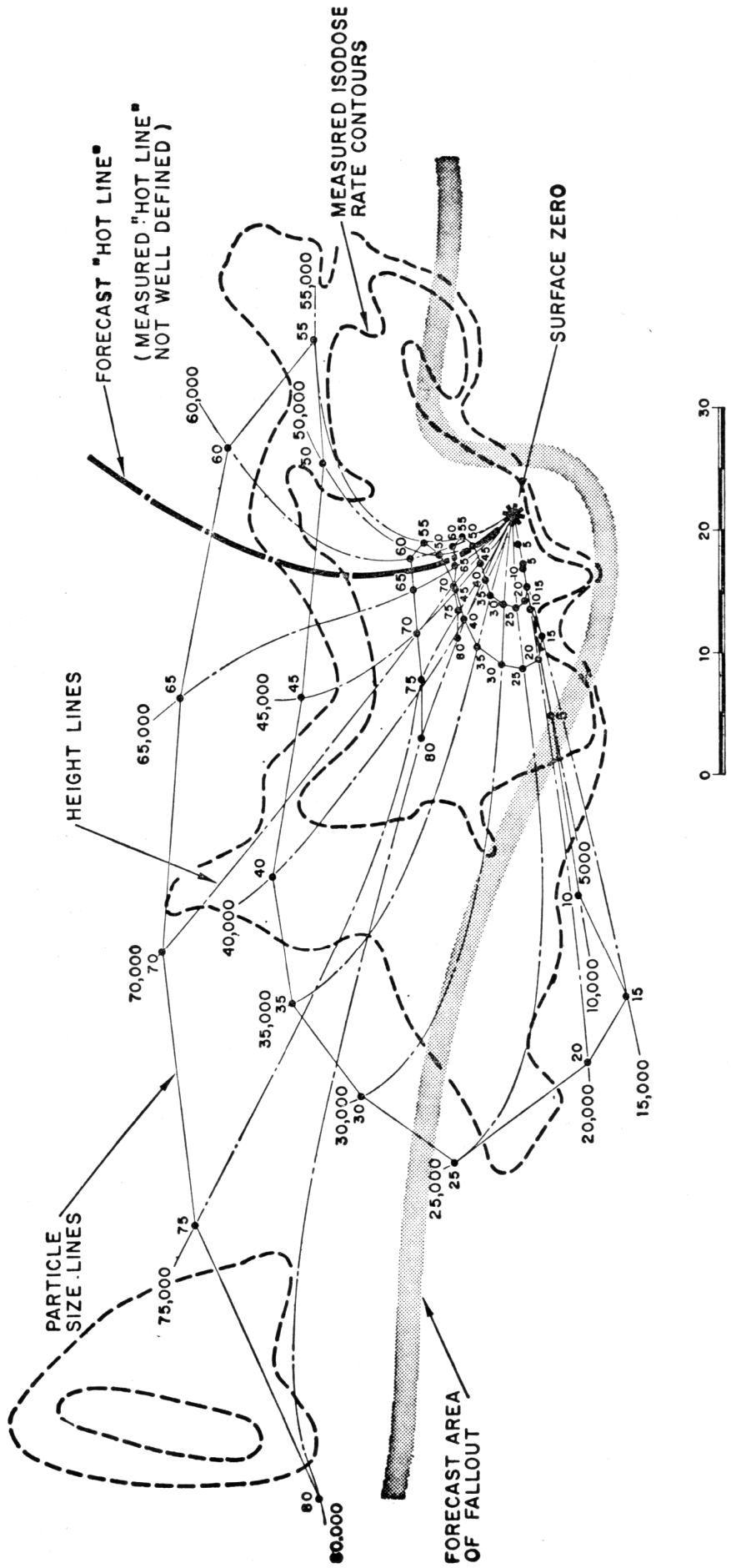

FIGURE 15.—*Comparison of fallout forecast with test results—shot D.*

MYRON B. HAWKINS (b. 1920), USNR, DL;

tion.[1 2 3 4] The contaminability of targets as related to micrometeorology and geometry have not been studied directly, but some information has been derived from experiments with other objectives.[5] As an example, a ship was exposed to fallout from a deep-water detonation.[6 7] The fallout arrived in a 15- to 20-knot wind on the starboard beam.

The following results were obtained:

(*a*) The contamination level (240 readings) on horizontal surfaces varied from 16 percent to 400 percent of the average, i. e., the largest was 25 times higher than the lowest.

(*b*) The gamma radiation level at 3 feet above the deck varied by a factor of 10.

(*c*) The average contamination level for vertical surfaces varied from the average horizontal reading as follows:

1. Forward part of the ship: 40 percent of horizontal average.
2. Aft part of the ship: 20 percent of horizontal average.
3. Lee side: 10 percent of horizontal average.
4. Windward side: approximately equal to horizontal average.

(*d*) Test panels at the stern of the ship had an average contamination level on vertical surfaces three times higher than levels on horizontal surfaces.[8]

Such data cannot be extrapolated or used for predictions without a better understanding of all of the factors involved.

In another example, small buildings and panels of typical building materials were exposed to fallout from land detonations.[4] The contamination levels on typical roofing materials was as much as 300 times higher than that on typical wall panels; or a vertical to horizontal relationship of about 0.3 percent. For panels of the same material, vertical readings were about 10 percent of the horizontal.

The two examples indicate considerable difference in the vertical to horizontal relationships. The characteristics of the fallout appear to have had a considerable influence on this distribution. For instance, the land detonation normally produces a "dry" fallout composed primarily of material from the crater. One can expect masses of 3 to 300 grams of material per square foot to be associated with significant radiation levels at early times. The fallout being a dry powder has little tendency to stick on vertical surfaces.

The fallout from deep-water detonations is largely composed of sea water salts. However, much of the water may evaporate, leaving particles that are damp, semicrystalline masses of a sticky nature. They are capable of sticking to vertical surfaces.

As indicated very little is known of the overall problem of contaminability. It is obvious, however, that two assumptions often made, i. e., ((1) that the fallout is distributed homogeneously on a uniform infinite plane, and (2) that vertical surfaces are not appreciably contaminated) are subject to serious limitations. The ability of a tactical force and/or a civilian population to exploit the variability of the fallout pattern depends upon knowledge we do not have on contaminability.

The contaminability of personnel exposed to the fallout event or working and living in contaminated environments is largely unknown. A study[9] indicating the significance of beta contact hazard to personnel and a requirement for the mass decontamination of personnel, emphasizes the need for additional contaminability information.

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[1] Gevantman, L. H., B. Singer, T. H. Shirasawa, Contaminability of Selected Materials, USNRDL—TR-11.

[2] Gevantman, L. H., J. F. Pestaner, B. Singer, D. Sam, Decontaminability of Selected Materials, USNRDL–TR–13.

[3] Lane, W. B., R. K. Fuller, L. Graham, W. E. Shelberg, Laboratory Studies of the Decontamination of Repeatedly Contaminated Surfaces, USNRDL–TR–59 (confidential).

[4] Strope, W. E., Protection and Decontamination of Land Targets and Vehicles, Operation Jangle, project 6.2, AFSWP–WT–400.

[5] Lee, H., M. B. Hawkins, Some Considerations of the Geometrical Distribution of Fallout Radiation Sources Over Targets, Proceedings of the Shelding Symposium held at USNRDL October 17–18, 1956, vol. II (USNRDL report in preparation), secret.

[6] Molumphy, G. G., Captain, USN, Bigger, M. M., Proof Testing of AW Ship Countermeasures, Operation Castle final report, project 6.4, USNRDL 0012361.

[7] Lee, Hong, Technical Survey Data for Operation Castle, project 6.4, USNRDL TM–49.

[8] Maloney, Joseph C., et al., decontamination and protection, Operation Castle, project 6.5, AFSWP–WT–928.

[9] Broido, A., Teresi, J. D., requirements for mass decontamination of personnel, USNRDL–TR–38, April 1955 (secret RD).

Cost of Reclamation

Considerable data has been collected regarding the effectiveness of reclamation of targets contaminated by local fallout. The feasibility of applying these methods depends upon the following parameters:

(*a*) The time required to perform the reclamation must be short enough to make an appreciable saving in radiological exposure to mission personnel,

(*b*) The radiation exposure to reclamation personnel must be justified by the saving in exposure of mission personnel,

(*c*) The effort (manpower) and logistics required to reclaim the target must be compatible with the total effort available.

Thus, the cost of reclamation as measured in operating time, effort, radiation exposure, equipment, and supplies is an important determination.

It is impossible to generalize on these quantities for they are influenced by many factors.

The type of fallout, whether it be from a deep water, harbor or land detonation, influences the rate and/or method of decontamination. A deepwater-type fallout can be removed only to an extent of about 60 percent for a firehosing, scrubbing operation on ships,[1] the rate being about 40 square feet per minute. The same decontamination procedure at 6 times the rate of operation on a paved area contaminated by dry-land-type fallout will yield a removal of about 98 percent.[2] To achieve an equivalent removal on the ship, a surface removal technique would be required. Typical rates of operation are about 20 feet per minute for paint stripping[3] and about 7 feet per minute for removing a ⅛-inch thick layer of wood from the flight deck.[4]

The amount (or mass) of fallout on a surface influences the rate, particularly for harbor and dry-type fallout that must be transported over horizontal surfaces for considerable distances. The following table shows an example of how the rate decreases with increasing masses of dry fallout for motorized flushing.[2]

Dry fallout gm/ft:[2]	*Motorized flushing rate, ft.²/min.*
10	670
33	650
100	580
330	300

The mass of fallout has no effect on the rate of operation for surface removal or earth moving techniques.

The rate of operation is influence by the surface characteristics of the target, rough surfaces, e. g., wood shingles, requiring longer time than smooth, e. g., metal surfaces. The following table is an example of the influence of surface roughness on rate of operation:[2]

Firehosing of dry contaminant

Material	Effectiveness (percent removed)	Rate (ft²/min/hose)
Corrugated metal	97	65
Composition shingles	95	50
Wood shingles	89	35

The rate of reclamation by earth moving is influenced by soil characteristics. Standard earth moving practice has developed considerable information on this subject.

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[1] AFSWP, ITR 1323, preliminary report, Operation Redwing, project 2.9, Standard Recovery Procedure for Tactical Decontamination of Ships. Confidential.

[2] Field Evaluation of Cost and Effectiveness of Basic Decontamination Procedures for Land Target Components, Sartor, J. D., Curtis, H. B., etc., USNRDL–TR in preparation. Unclassified.

[3] Rates approaching 50 square feet per minute are possible if removal of only the surface layer of paint gives the required reduction in radiation intensity.

[4] Proof Testing of AW Ship Countermeasures, Operation Castle, project 6.4 WT-927, Molumphy, Bigger. Confidential.

The degree of mechanization obviously influences rate of operation. The following example compares firehosing rate with that of motor flushing for harbor-type fallout. Also shown are the influence of mechanization on effort and radiation exposure.[2 5]

Criteria for comparison	Actual performance or cost		
	Firehosing	Motorized flushing	Relative cost FH/MF
1. Operating rate per unit, hr/10^6 ft^2	222	30	7.4
2. Personnel required per unit	5½	2	2.75
3. Effort (direct labor), man-hr/10^6 ft^2	1,210	60	20.0
4. Radiation shielding factor	1.0	0.5	2.0
5. Relative cost in radiation dose	1,210	30	40.0

Target complexity obviously influences rate of operation. For optimum performance, spacings between target components must be large enough to permit mechanized equipment to be used.

A simplified example will help indicate the time, manpower, and basic supplies required for recovery of a target complex. The following criteria are assumed:

(*a*) Target: City of San Francisco.
(*b*) Fallout: Harbor-type at 33 gms/ft^2.
(*c*) Area to be recovered: About 25 square miles consisting of—
1. All paved areas.
2. All industrial and commercial areas and buildings.
3. 50 percent of the park areas.
4. 10 percent of the residential areas and buildings.

(*d*) Methods: Firehosing and earth moving.

The following table indicates an estimate[5] of the cost of reclaiming these critical areas:

Cost of decontaminating critical areas of San Francisco through use of available firefighting and earth moving equipment for removing slurry contaminant

	Firehosing			Earth moving, land areas	Grand total
	Roofs	Paved surfaces	Subtotal		
1. Time to complete decontamination (24-hour days)	16.8	11.7	28.5	13	----------
2. Direct labor (number of men)	----------	----------	4,000	2,800	6,800
3. Total labor, direct and support (number of men)	----------	----------	6,000	4,900	10,900
4. Total effort (8-hour man-days)	101×10^3	70×10^3	171×10^3	64×10^3	235×10^3
5. Labor cost at $10 per man-day	----------	----------	1.71×10^6	0.64×10^6	2.35×10^6
6. Water required for decontamination (gallons)	362×10^6	314×10^6	676×10^6	----------	----------
7. Fuel required (gallons):					
(*a*) Gasoline	145,000	101,000	246,000	95,000	341,000
(*b*) Diesel fuel	----------	----------	----------	195,000	195,000

As can be seen, the reclamation is feasible in what appears to be a reasonable time. The amount of equipment required is within the capability of existing sources in San Francisco. The manpower is not too excessive considering the numbers of people available. The water requirements are within the capability of the normal supply. Fuel consumption is less than normal daily requirements. The greatest problem would undoubtedly be that of organizing, training, supervising, and controlling 11,000 men.

Automatic decontamination devices such as the washdown system have, as an important advantage, the capability of reclamation at very early times with no expenditure of manpower or radiation exposure. They can be extremely effective (i. e., removal of 90–95 percent) even on sea-water-fallout.[4] However, they do require expenditure of funds before the war begins.

[5] Engineering Approach to Radiological Decontamination, Hawkins, M. B. (Paper to be given ASME semiannual meeting, San Francisco, June 1957.) Unclassified.

Ess

Ess was an underground detonation which was fired at 12 p. m. on March 23, 1955. The shot took place in test area 10 in Yucca Flat.

No airway closure pattern was established for Ess.

The cloud was tracked as shown on the accompanying map from H plus 35 minutes to H plus 4 hours and 20 minutes. Tracking was accomplished between 10,000 and 13,000 feet by a B–25 type aircraft.

A low-level terrain survey was flown from H plus 3 hours to H plus 5 hours by 1 C–47. The results of this survey are shown on the accompanying map.

Monitoring runs, which indicated activity substantially above background, were made on U. S. 93 between a point 21 miles south of Alamo, Nev., and Glendale, Nev.; on the desert road north of Indian Springs, Nev.; and along several of the desert roads east of the Nevada test site.

The maximum effective biological dose for a populated area was 30 mr. at Beaver Dam, Ariz. The maximum effective biological dose at a nonpopulated point was 2,510 mr. 22 miles north of Indian Springs, Nev.

Approximately 105 individual monitoring readings above 0.1 mr./hr. were recorded.

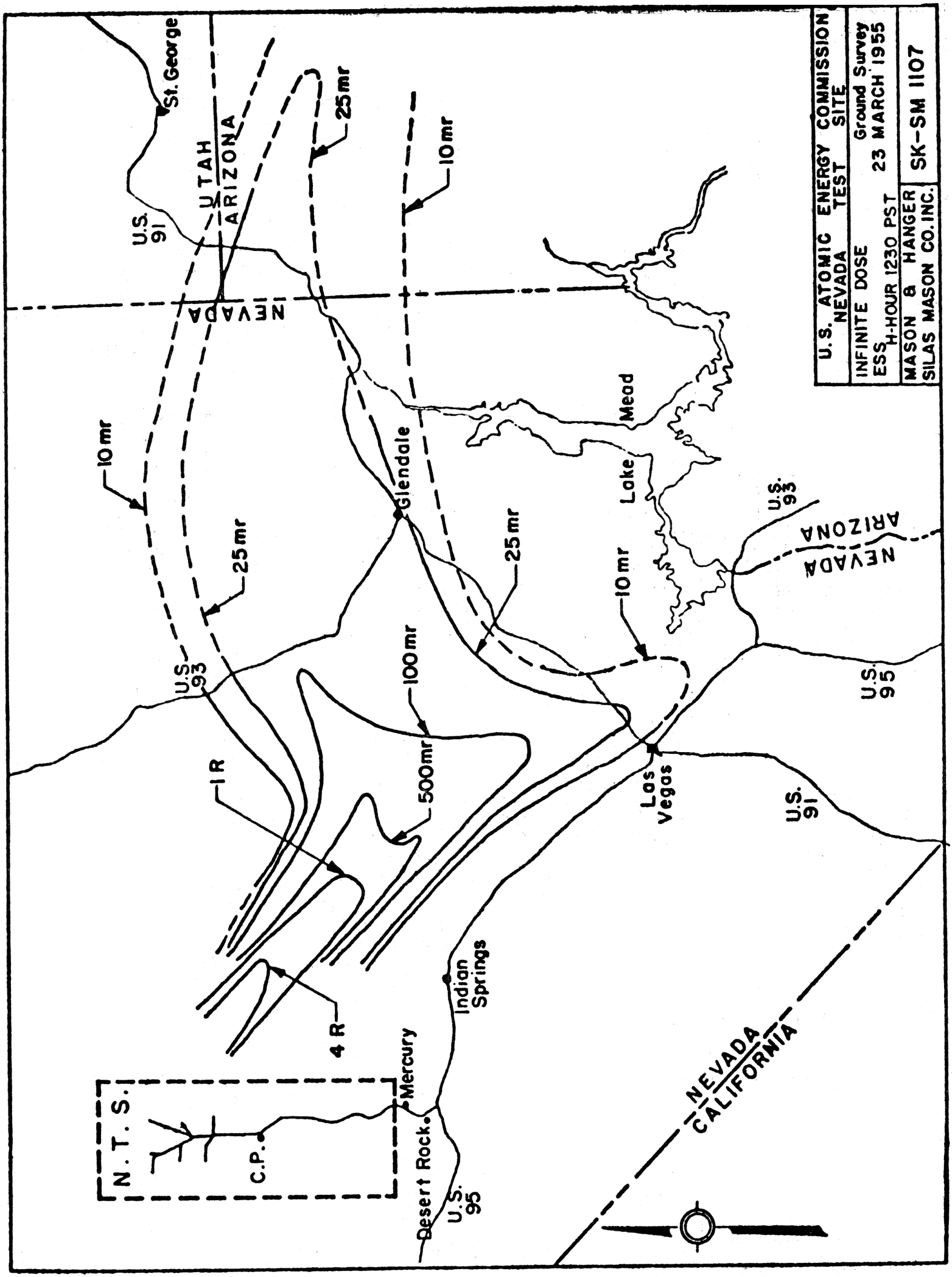
A comparison of the prediction map and the factual maps indicates good agreement in direction, but the 1 r. isodose contour was at least twice as long as was predicted.

The low-level terrain survey map shows roughly twice the infinite doses that are plotted from ground monitoring results. The leading edge of the cloud did not cross the eastern boundary of the bombing and gunnery range until approximately H plus 4 hours. The haze from the cloud could still be seen in the Valley to the east and northeast of Indian Springs, Nev., at H plus 5 hours. The higher dose indicated by the low-level terrain survey are, therefore, probably due to radiation from that part of the cloud still in the valley when the survey was made. The ground monitoring plot also indicates extensive shear and the effects of terrain features on fallout pattern. It is apparent from the maps that the 1 r. isodose contour did not intersect any major highways.

The maximum air radioactivity concentration measured was $4.5\times10^{-3}\mu c/m^3$, at Mesquite, Nev. This represents the average air concentration for a 43-hour period starting 1.5 hours after detonation.

Ess: External gamma dose in populated areas and at selected nonpopulated points

Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Nellis Air Force Base, Nev	3.5	0.8	3.5	8	14
Lake Mead Base, Nev	4.0	1.5	3.5	16	30
North Las Vegas, Nev	6.5	.3	3.5	7	12
Glendale, Nev	7.2	1.5	6.0	25	48
Moapa, Nev	20.9	.2	6.0	14	27
Beaver Dam, Ariz	23.6	.4	10.0	30	60
Nonpopulated points:					
U. S. 93, 38 miles south of Alamo, Nev.	6.3	3.0	6.0	51	100
22 miles north of Indian Springs, Nev.	5.3	140.0	2.0	2,510	4,400


U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE
Ground Survey
ESS H-HOUR 1230 PST 23 MARCH 1955
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UTAH
ARIZONA
NEVADA
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10 mr
25 mr
Glendale
Mead Lake
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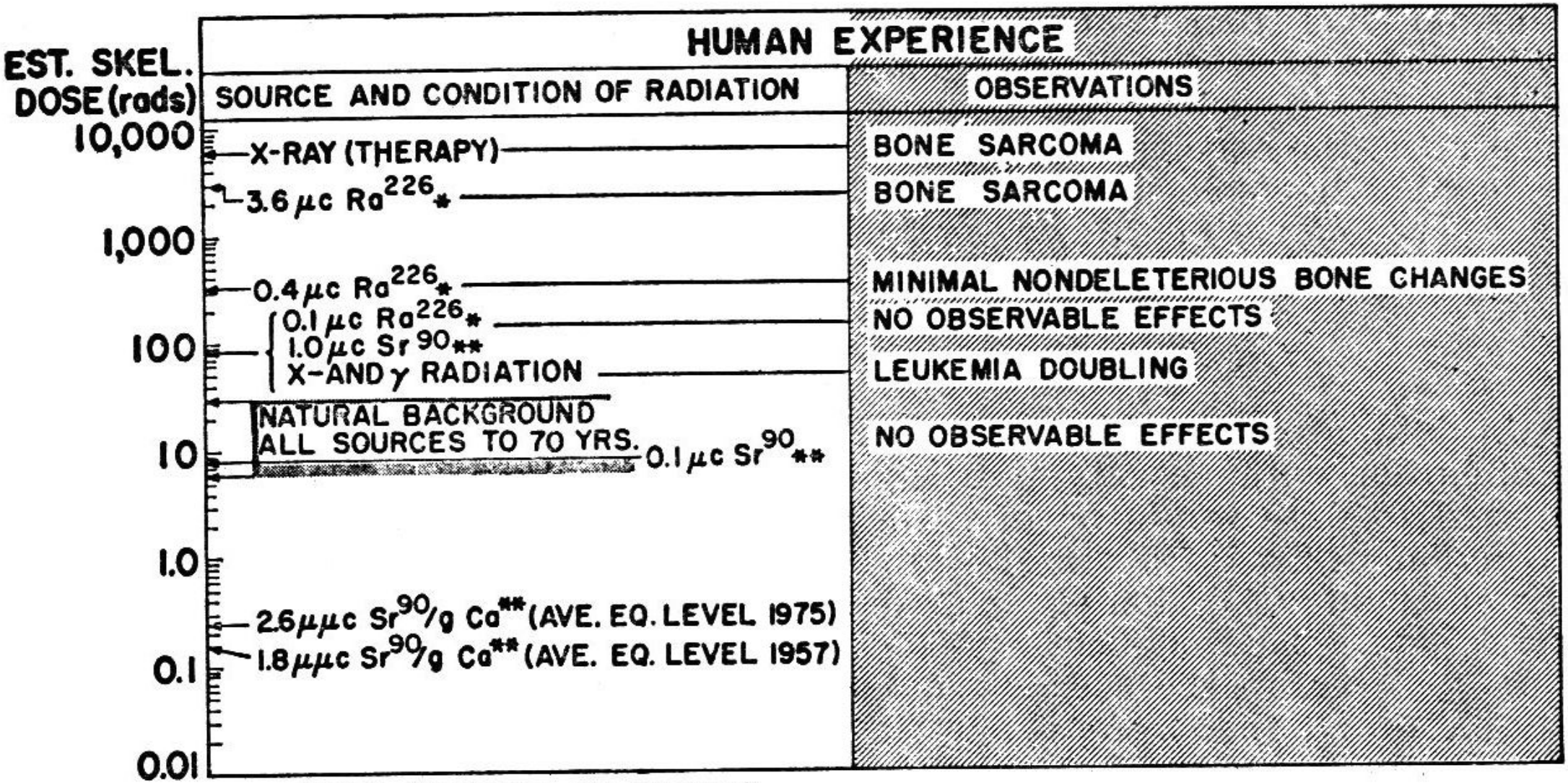
10 mr
U.S. 93
NEVADA
ARIZONA
U.S. 93
100 mr
500 mr
1 R
4 R
Las Vegas
U.S. 95
U.S. 91
Indian Springs
N. T. S.
C.P.
Mercury
Desert Rock
U.S. 95
NEVADA
CALIFORNIA



* FIXED IN BONE~25 YEARS

** CONSTANT FOR 20 YEARS, DECAYING WITH 28 YEAR HALF-LIFE TO AGE 70

THE NATURE OF RADIOACTIVE FALL-OUT AND ITS EFFECTS ON MAN

HEARINGS

BEFORE THE

SPECIAL SUBCOMMITTEE ON RADIATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

EIGHTY-FIFTH CONGRESS

FIRST SESSION

ON

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

JUNE 4, 5, 6, AND 7, 1957

PART 2

Printed for the use of the Joint Committee on Atomic Energy

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APPENDIX 10

OAK RIDGE NATIONAL LABORATORY,
Oak Ridge, Tenn., August 21, 1957.

Mr. JAMES T. RAMEY,
Executive Director, Joint Committee on Atomic Energy,
Washington, D. C.

DEAR MR. RAMEY: Enclosed please find a copy of the material concerning topic VIII D of the outline, fallout and water decontamination, requested by Congressman Holifield for the Joint Committee on Atomic Energy Report.

Enclosed is the biographical sketch also requested in your letter of June 19, 1957.

If I can be of any further assistance to you and the committee, please feel free to write.

Thank you.

Very truly yours,

WILLIAM J. LACY,
ERDL Representative at ORNL.

Enclosures: 1. Report on Fallout. 2. Biographical sketch.

Cc: Commanding Officer, Engineer Research and Development Labs, Fort Belvoir, Virginia; Harry N. Lowe, Jr., Chief Sanitary Engineering Branch, Fort Belvoir, Virginia; Dr. Karl Z. Morgan, Director, Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

BIOGRAPHICAL SKETCH

William J. Lacy was born in 1928 in Wallingford, Connecticut, attended Lyman Hall High School where he won the prizes in science and chemistry, then he obtained a B. S. degree in 1950 from the University of Connecticut where he majored in Chemistry. He entered graduate school at New York University in September of 1950 and worked as a research associate on an AEC research contract. In May of 1951 he joined the staff at the Engineer Research and Development Labs of Fort Belvoir, Virginia, and immediately was transferred to the Oak Ridge National Laboratory to work on the water decontamination research project.

He has had seven (7) articles published, presented numerous papers and is a member of the American Chemical Society, American Association for the Advancement of Science and the Scientific Research Society of America.

Mr. Lacy is married and has two (2) sons, 2½ and six months, he resides in Oak Ridge, Tennessee.

[Material for Joint Committee on Atomic Energy Topic VIII D]

REMOVAL OF RADIOACTIVE FALLOUT FROM CONTAMINATED WATER SUPPLIES

William J. Lacy, Chemist,* Sanitary Engineering Branch, Engineer Research and Development Labs, Fort Belvoir, Va.

There are two possible sources of radioactive contamination of public water supplies, (1) the result of direct discharge into the environment from reactor processing plants, research center using radioisotopes and others and (2) deposition of radioactive material by fallout or wash-in due to weapon's test activities.

Most of the radioactive materials in item one are in solution, fallout, however, may be in the form of insoluble oxides, and its removal may differ from the removal of ionic material.

Studies have been reported on the subject of fallout in particular areas (1), (2), (3), (4). It was reported that 35 percent of the fallout activity was removed by the Albany, New York, water treatment plant, an alum coagulation, settling and filtration plant. Thomas and his coworkers at Harvard (2) (3) working at the Lawrence, Massachusetts, water plant obtained 80 percent removal by coagulation, settling, and filtration. Bell (4) compared the fallout removal results from Cambridge and Lawrence, Massachusetts, and Rochester, New York, with pilot plant results obtained by Straub (5) (6) who used a simulated bomb blast mixture with an age about one month after detonation.

*On loan to Health Physics Division, Oak Ridge National Lab., Oak Ridge, Tennessee.

The comparison indicated the three treatment plants show much lower removals of fallout than Straub obtained on chemical processed radioactive material even though the same procedure was used in both cases. The U. S. P. H. S. reported the analysis of rain water samples containing fallout showed 50 to 100 percent of the "old" radioactive material to be soluble. However, the soluble fraction dropped to about 30 percent during the weapon's testing period.

For reactor made fission products, or a mixture of commercially available radioisotopes, the efficiency of removal would be a function of the various radioelements comprising the mixture. Results in laboratory studies and pilot plant scale investigations by the author indicates removals of about 70 to 85 percent using either alum and soda ash or ferric chloride and limestone coagulants. A series of studies (7) reported that removals of 99 percent could be obtained using a serial coagualtion procedure including an excess lime-soda ash softening or phosphate coagulation step, provided some clay material was added to remove radiocesium.

Conventional wastes treatment processes include coagulation, settling, and filtration, plus disinfection. Often additional treatment, such as fluoridation, aeration, softening, ion exchange, iron and manganese removal are employed.

During coagulation certain of the dissolved constituents are precipitated as insoluble hydroxides or carried along, scavenged, with the heavy metal hydroxides of alum or iron. Coagulation can have its radioactivity removal increased from about 75 percent to almost 90 percent by the addition of clay for cesium and copper sulfate for radioiodine.

It should be pointed out that different radioisotopes respond differently to removal by coagulation. Other factors to be considered include: (1) Chemical and physical form of the radionuclide, (2) concentration or the radioactive material, and (3) optimum pH of flocculation for the coagulant available and the water under treatment. Investigation by the author (8) indicates increase dosages of chemical generally yielded only slightly higher removals while higher pH usually resulted in proportionately higher removals.

Softening using lime-soda ash is one of the more effective chemical methods for the removal of radiostrontium and barium. However, it is necessary to use excesses quantities, over the stoichiometric dosage, for satisfactory results. Studies at MIT (9) (10) have indicated that the radiostrontium is removed by coprecipitation with the hardness or calcium carbonate in a mixed crystal formation.

Ion exchange is another method used by some municipal water treatment plants. Removal of ionic radionuclides by this process is not only technically possible (11), but very satisfactory. The most effective method employes either a mixed bed principal or separate cation-anion exchange columns. Ion exchange units such as home-type water softeners are very effective for removal of 99+ percent of the radioactive fallout or reactor originated radionuclides from contaminated water. Also ion exchange resins (mixed) can be used with, good results, as slurries for the removal of a vaniety of radioactive contaminants from water solutions (12)

Other methods, such as, the use of clays, powdered metal, charcoal, flotation and various adsorbents all have some merit for the removal of specific radioisotopes or under a given set of condition result in good removals. (13) However, clay seems to have the most practical and over advantage of being (1) available, (2) cheap, (3) effective, (4) simple to use, (5) easy to remove both absorbent and absorber and the radioactive material will not be easily leached once it is attached to the clay particle. Distillation although not a usual municipal water treatment method is used extensively by the military on island bases and where a high quality of water is required. Distillation results in the best single treatment of a contaminated water removing 99.9+ percent. (14) The major objection to distillation as a water treatment procedure is cost.

As indicated by the literature cited most of the above studies have been made on chemically processed, radiochemically pure radioisotopes and not true fallout from a nuclear detonation. Therefore, it was expected that the actual fallout material not being entirely in the same physical and chemical form could not be as readily removed from contaminated water. However, recent tests by the Corps of Engineers at the AEC Nevada Proving Grounds on some very low level fallout indicated (1) close agreement with laboratory results on removal by coagulation and softening using lime-soda ash and precipitation with trisodium phosphate at a high pH, (2) the ion exchange procedures resulted in 99 to 100 percent removal of the bomb fallout material, (3) the material that was not

a true solution could be removed physically and the material in solution treated chemically and (4) radionuclide once adsorbed on clays were not appreciably leached by tap water.

Many other experiments have been made by myself and others, some are still in progress, which have not been cited here. It is felt that this brief general review plus the six tables showing detailed data, will give the committee a review of the field on water decontamination.

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TABLE I.—*Coagulation for removal of radioactivity*

Contaminant	Dosage, p. p. m.	Percent removal	
		$FeCl_3$–$CoCO_3$	Alum-soda ash
Ce^{144}–Pr^{144}	50	99.2	96.1
	100	99.4	96.5
Ba^{140}–La^{140}	50	67.4	58.4
	100	70.7	58.0
Zr^{95}–Nb^{95}	50	98.1	76.4
	100	98.8	78.6
I^{131}	50	45.0	26.3
	100	63.0	35.7
P^{32}	45.7	93.3	94.1
MFP-1 [1]	29–58	60–83.7	----------
MFP-2 [2]	50	70.1	72.6

[1] MFP-1—ORNL waste containing mixed fission products.
[2] MFP-2—Simulated 30-day atomic-bomb blast mixture.

TABLE II.—*Results of lime-soda ash treatment for removal of strontium*

Treatment	Percent removal of activity
Stoichiometric amounts	75.0
20 ppm excess lime-soda ash	77.0
50 ppm excess lime-soda ash	80.1
100 ppm excess lime-soda ash	85.3
150 ppm excess lime-soda ash	97.3
200 ppm excess lime-soda ash	99.4
300 ppm excess lime-soda ash	99.7

TABLE III.—*Ion exchange column for water decontamination*

Run No.	Resin*	Contaminant	Resin capacity gal./ft.^{3}	Percent removal until breakthrough
1	Cation	MFP-1	5,700	71–82
2	Mixed bed	MFP-1	3,150	93–99+
3	Cation	MFP-2	6,000	88–96
4	Mixed bed	MFP-2	2,890	96–99
5	Cation	Zr^{95}–Nb^{95}	6,750	85–88
6	Mixed bed	Zr^{95}–Nb^{95}	2,600	92–97
7	Cation	MFP-3	3,270	85–90
8	Mixed bed	MFP-3	6,150	92–99

*Cation resin was a high capacity nuclear sulfonic acid type and mixed bed was amberlite MB-3.

NOTES

MFP-1—ORNL liquid waste material.
MFP-2—Simulated 30-day atomic-bomb debris.
MFP-3—Three year old dissolved reactor fuel element.

TABLE IV.—*Removal of radioactive contaminants from water—Resin-jar test studies (stirring time, 90 minutes, samples filtered)*

Contaminant	Initial pH	Initial activity c/m/ml	Percent removal mixed ion exchange resin, p. p. m.			
			450	900	1,800	2,700
P^{32}	8.2	5,560	47.4	74.5	96.2	99.8
Cd^{115}	8.0	7,880	37.9	45.6	91.1	99.99
Cs^{137}–Ba^{137}	8.2	8,200	15.1	14.6	69.1	99.99
Zr^{95}–Nb^{95}	8.1	6,700	98.3	98.4	99.2	99.4
I^{131}	7.5	3,200	84.5	93.5	95.6	98.1
Ce^{141}, ^{144}–Pr^{144}	7.9	4,150	98.7	99.2	99.8	99.98
Ba^{140}–La^{140}	7.6	3,490	85.1	94.5	98.8	99.9
FPM-4	8.3	13,600	82.7	90.5	97.3	99.2
FPM-5	2.7	3,400	38.4	----	----	----

NOTES

FPM-4—Iodine dissolver solution aged 30 days.
FPM-5—Mixed fission product waste containing mainly Cs^{137}–Ba^{137} and Ru^{106}–Rh^{106}.

TABLE V.—*Decontamination of radioactively contaminated water by slurrying with clay*

Contaminant	pH	Clay concentration, p. p. m.	
		1,000	3,000
		Percent removal	
Ru^{106}-Rh^{106}	5.2	50.5	61.5
Zr^{95}-Nb^{95}	7.5	98.0	99.4
Sr^{90}-Y^{90}	7.7	83.4	92.9
I^{131}	7.5	4.9	3.4
$Ce^{141,144}$-Pr^{144}	8.0	99.7	99.9
Ba^{140}-La^{140}	7.8	88.8	94.3
MFP-1	8.8	82.0	86.3
MFP-2	9.0	70.0	72.8
MFP-3	7.7	79.0	83.6

TABLE VI.—*Removal of radioactive material by distillation (60 gallon/hr thermocompression unit)*

Run No.	Contaminant	Activity of feed, d/m/ml	Removal of activity expressed as decontamination factor	Percent
1	MFP-1	22,060	4.10×10^3	99.98
2	MFP-2	97,400	4.97×10^3	99.98
3	MFP-3	31,150	3.59×10^3	99.97
4	MFP-4	62,400	3.52×10^2	99.72
5	Pa^{233}	41,030	2.31×10^3	99.96
6	I^{131}	60,900	7.04×10^2	99.86
7*	MFP-5	38,910	1.09×10^3	99.91
8*	MFP-4	69,700	1.00×10^4	99.99
9*	MFP-1	12,020	1.70×10^4	99.99
10*	I^{131}	45,600	1.28×10^3	99.92
11*	Pa^{233}	25,300	5.80×10^3	99.98

*Glass wool reflux condenser used.

NOTES

MFP-1 was 3-year-old fission product mixture.
MFP-2 was a 2-week-old mixture from disolution of a reactor slug.
MFP-3 was composite sample or ORNL liquid waste.
MFP-4 concentrate from ORNL liquid waste evaporator.
MFP-5 mixture to simulate the material expected 10 days after atomic detonation.

APPENDIX 11

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington 25, D. C., August 20, 1957.

HON. CHET HOLIFIELD,
Chairman, Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, House of Representatives, Congress of the United States.

DEAR MR. HOLIFIELD: At the suggestion of your Committee, the Division of Biology and Medicine, U. S. Atomic Energy Commission, invited the principal participants in the discussions involving predictions of future skeletal concentrations of strontium 90 in humans which took place at the recent Congressional Hearings on fallout to meet once again in an attempt, insofar as present information permitted, to reduce the degrees of uncertainty in these predictions.

This meeting took place on July 29, 1957 and I am pleased to transmit a summary report of the meeting based on the stenographic transcript and consultation with the principal participants. This report was prepared by Dr. Forrest Western, of the Division of Biology and Medicine. It is my opinion this report honestly and clearly reflects the views of the participant scientists with respect to this problem. This document, then, would appear to reflect the thinking of those scientists who have worked hardest and thought most on the subject of these predictions, and should, therefore, be a useful addition to the text of the very important and

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